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UNIVERSITY OF ALBERTA

NITROGEN DYNAMICS DURING RICE CULTURE USING *SESBANIA ROSTRATA* AS GREEN MANURE IN NORTHEAST THAILAND

BY

BRYAN RODERICK HAMMAN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

IN

AGRONOMY

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EDMONTON, ALBERTA

SPRING 1991

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SUBMITTED BY BRYAN RODERICK HAMMAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MSc.

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Dedication

The blessing of the Lord God has been upon me since the beginning of this project. Often my life was in danger, but He spared me. The blessings also included: rain and sunshine in the right seasons; people who were willing to help me for little or no pay; and the way all things seemed to work out just right. The day that I received the scholarship to do this research, I said to my God "All that is mine is yours because you have given it to me." Now that the project is finished I maintain that all the honour and glory are God's. Therefore, this work is dedicated to God in the name of Jesus Christ.

ABSTRACT

Sesbania rostrata is a stem nodulated legume from Senegal, West Africa, which has been proposed as a salt-tolerant green manure crop for the tropics. This research examined its effectiveness as a green manure to improve soil fertility by increasing the supply of NH_4^+-N from biological N_2 fixation in fine to coarse-loamy isohyperthermic Alfisols and Ultisols in Northeast Thailand.

Under the conditions of this study, the growth period of *S. rostrata* varied between 58 and 93 days. The longer a stand of *S. rostrata* grew, the more N was accumulated (*e.g.* 51.7 kg of nitrogen ha^{-1} in 93 days). When supplied with 37.5 kg ha^{-1} of K_2O, and of P_2O_5, yields increased and accumulated N increased (*e.g.* 267 kg ha^{-1} in 93 days). An exponential model fitted to the data indicated that concentrations of NH_4^+-N in soil after plough down of fertilized *S. rostrata* were greater than for either the treatment using *S. rostrata* alone or for the control. Concentrations of NH_4^+ rose quickly and remained constant, potential ammoniacal N values varied between 6.5-30.8 mg kg^{-1}, and rate constants were high. In the absence of a rice crop, the recovery of N added as green manure varied between 5.8 and 16.4%. It was inferred that losses by volatilization equalled mineralization.

Consistently over 30% of the N in the above ground parts of determinate tall rice crops was derived from ^{15}N labelled *S. rostrata* green manure. Recovery of added N in the grain plus straw, calculated by the Difference Method, was 14-27%; when calculated by the Isotopic Method, it was 11-13%. As much as 78% of added N was lost or immobilized in the soil. From 11-40% of *S. rostrata* ^{15}N was detected in the soil after the rice harvest. Therefore, losses must have been significant and volatilization is proposed as the most probable cause. With P and K fertilized *S. rostrata* rice yields were increased 2.5 fold on sandy, nonsaline soils. Rice yields on saline (12 dS m^{-1}) soils were poor, and showed no treatment effects. Straw yields responded most clearly to the improved N regime, although rice yields also increased in the absence of drought or high salinity.

It was concluded that: i) NH_4^+-N release begins immediately following plough down, and NH_4^+-N concentration in the soil reaches a steady state within an average of 16 days; ii) in excess of 30% of N in subsequent rice crops is derived from the *S. rostrata*, and a doubling or tripling of yields can be achieved with green manure on a nonsaline soil; and, iii) 11-13% of the N from *S. rostrata* is transferred to the rice, 11-40% remains in the soil, and the rest is leached or volatilized. The agronomic implication is that *S. rostrata* green manure can supply N to paddy rice in Northeast Thailand, but immediate transplanting and other ways should be found to increase N conservation within the soil-plant system.

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CHAPTER 1 INTRODUCTION

1.1 Background

The agronomic limitations of infertile, sandy, saline soils affect 18 million people living on the 17 million hectares of Northeast Thailand - one third of the country both in population and area. Eighty percent of this population live directly off the land. Annual per capita income for a six person household is 1874.76 US$. This is substantially lower than the national average, because agricultural output is low. While the Northeast plants 46% of the country's total paddy rice, it contributes only 35% to the national harvest (Prapertchob, 1987). Although there is a potential threat from the salt underlying the Northeast, the primary limit to rice production is poor soil fertility.

1.2 Geography

The region (lying between 101° and 105° east and 14° and 18° north) is bounded by mountains to the west, south, and northeast, and is divided latitudinally by the Phu Phan mountain range into the southern Korat basin and the northern Sakon Nakorn basin. The topography is gently undulating, except near the mountains in the west or south, where isolated mesa and cuesta occur. The basins are underlain (starting at 30 m) by rock salt deposits (Arunin, 1983).

During the rainy season from May to October, rainfall is erratic (whether from equatorial or tropical cyclonic systems, or local thunderstorms). Annual precipitation is ~1447 mm, which is less than the ~1729 mm of annual evaporation. Soil water-logging during the rainy season, however, is common. Daily temperatures average 32° C. The native vegetation of the lowland areas is primarily a deciduous Dipterocarp forest.

Extensive land clearing (deforestation) for lowland rice is considered the cause of saline ground water rising to within two meters of the surface during the rainy season (Ernst Loffler, pers. com., 1987; Peck et al., 1987). Salinization occurs because the saline water then moves to the surface by capillary rise. In the dry season, the water table drops below 2 m and capillary rise ceases. Intentional dyking of the land for rice culture limits surface drainage such that salts precipitate on the soil surface (Arunin, 1983).

1.3 Soils

Infertile Ultisols with acidic, fine sandy-loam surface horizons are common in the study area. The soil is coarse textured and has a low water-holding capacity, and water deficiency is problematic even during the rainy season. Clay content, principally kaolinite, ranges from 5 to 10%, while organic C is about 5.0 g kg^{-1} (or total N is about 0.5 g kg^{-1}). The resultant cation exchange capacity (CEC) is 0.1 to 3 $cmol_c$ kg^{-1} (Willett, 1987). Rice grown on this soil suffers from N-deficiency. It is yellow, stunted, poorly tillered with small poorly filled panicles. To produce a rice crop which does not suffer from N deficiency, 1.8-2.0 g N per 100 g of grain is required (Yoshida, 1981). Alternatively, the critical limit of total soil N is estimated to be 2.0 g kg^{-1} (Ponnamperuma and Lantin, 1985).

Saline (*viz.* 95% NaCl) soils, with an electrical conductivity of the saturation extract (ECe) of 4.0 dS m^{-1} or more, cover 18% of the Northeast - and the extent is expanding (Arunin, 1983). Although rice is moderately salt tolerant, grain yields decline by 50% in the ECe-range of 4.0-10.0 dS m^{-1}. As salt concentrations increase, the osmotic potential in the plant becomes more negative and water stress occurs. Sodium and Cl^+ ions accumulate, damaging tissues, and inhibiting uptake of N and P (USDA Staff, 1954; Yoshida, 1981). Tolerance to salinity is greatest during the germination stage, whereas the seedling and flowering stages are most sensitive. Flooding increases tolerance by diluting the salt. Rice can then survive an ECe of 20.0 dS m^{-1} in the saturated paste extract (Abrol *et al.*, 1987).

1.4 Current Management

Improving rice yields is a priority for all farmers in the study area, whether or not their land is saline. The paucity of soil N has not, however, been redressed by adding chemical fertilizers. The near absence of clay results in poor retention of added nutrients and poor buffering against fluctuations in pH caused by wetting and drying or the hydrolysis of water by chemical fertilizers (Ragland *et al.*, 1986). Thus, yields of rice in Northeast soils with low CEC are unpredictable. The yield of rice grown on soils with a greater clay content (the less common Phimai series at ~40%) increases with addition of chemical N fertilizers (Ragland and Boonpuckdee, 1986; Ragland and Arunin, 1987). The poor yield response of rice to chemical fertilizers makes use of these amendments unprofitable. This is exacerbated by the fact that the cost of chemical fertilizers in Thailand is high compared to *per capita* income (Fuglie, 1986; Arunin et al., 1988). For example, in 1988-89, 50 kg of 0-0-60 cost 14.00 US$, 50 kg of 0-46-0 cost 19.00 US$, and 50 kg of 46-0-0 cost 11.00 US$.

1.5 Proposed Management

Efforts to ameliorate these soils, therefore, depend upon adding essential nutrients and improving the soil's ability to retain these nutrients. The socio-economic condition of the Northeast was a determining factor for the type of soil improvement system studied, and reported in this thesis. The management system required that: 1) it fit into the traditional rice culture; 2) it used available equipment; 3) it could be implemented without large capital expenditures; and, 4) it supplied the staple rice crop with sufficient N to increase yields. Green manuring (the practise of incorporating easily decomposable, usually leguminous, plant material) was suggested to meet the above criteria.

The ideal green manure crop does not demand extra land, labour, soil moisture, or other inputs that would otherwise be used for the primary rice crop (Singh, 1983). Consequently, it must be possible to plough down the green manure immediately before the rice is transplanted. (Khinde *et al.*, 1985, Khinde *et al.*, 1982, and Beri and Meelu, 1981). The greater the biomass the greater will be the expected N addition, so that rapid growth with high biomass production and N fixation are desired attributes.

Sesbania rostrata, an annual stem-nodulating legume from Africa, sown in May or June (when the first rains fall) can accumulate N at equivalent to 148-176 kg ha^{-1} in 40-60 days, respectively (Marqueses *et al.*, 1985 and Dreyfus *et al.*, 1983). Rice grain yields, total dry matter yield, N uptake and productive tillers of rice in the Philippines were markedly affected by *Sesbania aculeata*, *Sesbania "China type", and S. rostrata* green manure, but particularly by *S. rostrata* due to its tolerance of flooding (Furoc *et al.*, 1985, and Centeno *et al.*, 1985). Green manure from *Sesbania aculeata, Crotolaria juncea, Dolichos lablab, Glycine max* incorporated into flooded soils raised ammonium concentrations over those of the nonfertilized control (Meelu, *et al.*, 1985). Similarly, Rinaudo *et al.*, 1983, observed that 2/3 of the fixed N in the *S. rostrata* plant was released to the soil. The use of indigenous practises and equipment (i.e. water buffalo) with *S. rostrata* as green manure prior to rice culture has been documented by Gines *et al.*, (1986).

Sesbania rostrata has attributes which make it a suitable candidate for green manuring in the Northeast: rapid growth, tolerance of flooding (because of its aerenchyma tissue), and salinity tolerance (from 0.08-8 dS m^{-1} and higher yields at 4 dS m^{-1} than at 0.08 dS m^{-1}) (Awonaike, 1988; Marqueses et al., 1985; and Evans and Rotar, 1987). Other candidates which have been tested (*Sesbania speciosa, Sesbania cannabina, Sesbania aculeata,* and *Crotolaria juncea*) possess some but not all of these essential characteristics (Arunin *et al.*, 1988). The fast growing rhizobia that infect *S. rostrata*, ORS-571, are specific and innoculation is necessary (Rinaudo *et al.*, 1983).

This research investigated the use of *S. rostrata* as a green manure to improve soil fertility for rice cropping in Northeast Thailand. Three conditions must be satisfied if the new management system were to be adopted: (1) use of fertilized green manure incorporated into the soil must increase the N supply to and yield in rice; (2) the pre-rice land preparation, use of fertilizer, and green manure incorporation must not interfere with the traditional farming methods; and (3) the value of the improved rice yields must offset the expense of growing the green manure. The project was conducted using farm plots, to test the improvement in rice yields. Condition 3 was not directly tested by the research reported in this thesis although some observations were made, and conclusions drawn.

The first overall hypothesis was: Nitrogen from *S. rostrata* is transferred to rice in measurable quantities. Due to the poor nutrient regime of Northeast soils, the green manure itself required a starter rate of P_2O_5 and K_2O fertilizer (37.5 kg ha^{-1} of each). The judicious use of chemical fertilizers, particularly P, is associated with increased legume production (Meelu and Morris, 1988, Ragland and Arunin, 1987, Heichel and Barnes, 1984, and Abrol and Palaniappan, 1988). The second overall hypothesis, then, was that green manure plus P and K fertilizer increases rice grain yields on either sandy or saline soils.

1.6 The Experiments

1. **AVAILABLE NITROGEN:** Rice is unique in that it is able to utilize high concentrations of ammonium-N. A high, available-N concentration in the soil, therefore, is beneficial to rice crops. The overall objective for this experiment was to examine N mineralization under field conditions from *S. rostrata* incorporated into paddy soils, and relations between N supply and rice production.

2. **NITROGEN TRANSFER TO RICE:** Green manures decompose once they are incorporated into the soil. The objective of this experiment was to determine how much of the N fixed in the green manure (*S. rostrata*) was re-mineralized and utilized by the rice plants.

3. **RICE YIELDS:** Nitrogen from decomposed green manures improves the yield of the subsequent rice crop. The objective of this experiment was to determine which treatment(s) gave the best rice yields. The pre-rice treatments were green manure without P and K fertilizer; green manure with P and K fertilizer; and no green manure.

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CHAPTER 2 AMMONIUM NITROGEN IN TWO SANDY, SALINE SOILS IN NORTHEAST THAILAND FOLLOWING INCORPORATION OF SESBANIA ROSTRATA AS GREEN MANURE

2.1 Introduction

The greatest quantities of N utilized by rice are required during the vegetative stage, although N applied at the panicle initiation stage increases the number of spikelets and N applied at the reduction division stage increases total mass of grain. Excessive quantities of N supplied at the end of the vegetative stage decrease yields due to lodging and reductions in stored carbohydrate (Murata and Matsushima, 1975). Exchangeable NH_4^+ is the most important available soil N fraction for flooded rice. Although rice can utilize NO_3^-, oxidation of NH_4^+ to NO_3^- occurs only in isolated aerobic zones (Keerthisinghe *et al.*, 1985; Mengel and Viro, 1988; Yoshida, 1981). Ammonium-N, however, is subject to volatilization, fixation on the cation exchange complex, and immobilization by living organisms other than the main rice crop. Therefore, to reduce potential losses, application of N amendments needs to be coordinated with plant demand (DeDatta, 1981; Freney *et al.*, 1981; Keerthisinghe *et al.*, 1985).

The paucity of soil N supply in the Northeast of Thailand has not been redressed by addition of chemical fertilizers. The near absence of clay results in poor retention of added nutrients and poor buffering against fluctuations in pH caused by wetting and drying or the hydrolysis of water by chemical fertilizers (Ragland *et al.*, 1986; Mengel and Viro, 1988; Tolley-Henry and Rapes, 1986). Yield results in Northeast soils, with low CEC, are unpredictable. Efforts to ameliorate these soils, therefore, depend upon adding essential nutrients and improving the soil's ability to hold them. Thus, green manuring, the practise of incorporating easily decomposable (usually leguminous) plant material, has been suggested to meet these criteria. The effect of green manure (e.g. *Sesbania aculeata, Crotolaria juncea, Dolichos lablab, Glycine max*) incorporation into flooded soils was to raise NH_4^+-N concentrations over those of the unfertilized control (Meelu, *et al.*, 1985). Similary, in Senegal, Rinaudo *et al.* (1983) observed that 2/3 of the fixed N in the *Sesbania rostrata* plant was released to the soil.

Sesbania rostrata, an annual stem-nodulating legume from Senegal West Africa, has attributes that make it a suitable candidate for green manuring in the Northeast: rapid growth, tolerance of flooding and tolerance of salinity (up to 8 dS m^{-1}) (Arunin *et al.*, 1988; Awonaike, 1988, Marqueses *et al.*, 1985, and Evans and Rotar, 1987). Neverthless, green manure itself may require P and K fertilizer to increase its biomass and quantity of N fixed (Meelu and Morris, 1988; Ragland and Arunin, 1987; Heichel and Barnes, 1984; Abrol and Palaniappan, 1988).

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This research examined the effectiveness of *S. rostrata* as green manure to improve soil fertility (by increasing the concentration of NH_4^+-N in the soil) for rice cropping in Northeast Thailand. The hypotheses for this experiment were: (1) NH_4^+-N accumulates following incorporation of *S. rostrata* green manure despite the low CEC of the soils; (2) decomposing P and K fertilized *S. rostrata* green manure supplies more NH_4^+-N than the non-fertilized *S. rostrata* green manure, and the control; and, (3) salinity reduces the concentration of NH_4^+-N in the soil.

2.2 Methods and Materials

2.2.1 Sites and soil description

Site 1 - DM88 and DM89

The Don Mong (DM in 1988 and 1989) site is ~30 km west of Khon Kaen City. Annual precipitation averages 1177 mm. The soil has 50% sand and 10% clay in the 20 cm thick Ap horizon. The study area is a lower terrace with a 1-2% slope. Flooding occurs annually to a maximum depth of 20 cm for about 2-3 months. The soil is a coarse-loamy, siliceous, isohyperthermic Aeric Paleaquult (USDA Soil Taxonomy), with pH of the Ap horizon = 5.5; N = 0.5 g kg^{-1}; P = 32 mg kg^{-1}; and, ECe = 0.3 dS m^{-1}.

Site 2 - PYa88 and PYa89

The Pra Yeun (PYa in 1988 and 1989) site is ~30 km southwest of Khon Kaen City. Annual precipitation averages 1177 mm. The soil has 67% sand and 5% clay in the 20 cm thick Ap horizon and is saline. The area used is a low terrace with a 1-2% slope. Flooding occurs annually to a maximum depth of 20 cm for about 1-2 months. The soil is a fine-loamy, siliceous, isohyperthermic Typic Natraqualf (USDA Soil Taxonomy), with a pH of the Ap horizon = 7.0; N = 0.2 g kg^{-1}; P = 49 mg kg^{-1}; and, ECe = 12 dS m^{-1}.

2.2.2 Experimental design

The experiment included three treatments and four replications in a completely randomized design. The average plot size was 2.7 m^2 at PYa, and 5.7 m^2 at DM, the non-saline site. The treatments were: (1) Fertilized *S. rostrata* green manure (FGM); (2) Nonfertilized *S. rostrata* green manure (GM); and, (3) Control with no *S. rostrata* green manure or fertilizer (CTL).

2.2.3 Green manure production

Sesbania rostrata seed that had been soaked for two days to break dormancy was broadcast onto the plots at a rate of 30 kg ha^{-1}. The seeding date depended upon adequate rainfall, and varied between sites and years. Consequently, seeding at Don Mong was May 23 in 1988 and

May 11 in 1989; while at Pra Yeun seeding was June 21 in 1988 and June 14 in 1989. The fertilized plots received (P_2O_5 @ 37.5 kg ha^{-1}) and (K_2O @ 37.5 kg ha^{-1}), broadcast when the plants reached ~10 cm. Green manure incorporation also depended on adequate rainfall to flood the paddies, which would allow easy ploughing and rice transplantation (See Appendix 1). At Don Mong incorporation was August 23 in 1988 and August 2 in 1989; at Pra Yeun incorporation was September 6 in 1988 and August 12 in 1989.

2.2.4 Green manure incorporation and soil preparation

The green manure in each plot was uprooted, washed, and weighed. A sample of the green manure was taken for analysis of moisture content and total N. The soil of the plots was ploughed by hand, and a soil sample was taken from each plot. Then the green manure, chopped into 15 cm lengths, was incorporated by foot into the soil of the flooded plots. The aim was to incorporate the green manure into the reduced layer to minimize N losses following ammonification because experience with nitrogen fertilizers in paddy soils has been that surface applications are subject to high losses (DeDatta, 1987; Sen and Bandyopadhyay, 1987).

2.2.5 Sampling procedure

After *S. rostrata* green manure incorporation, soils in each plot were sampled on a periodic basis. In 1988, samples were collected 20 times in 70 days at Don Mong, and 23 times in 70 days at Pra Yeun. In 1989, samples were collected 22 times in 63 days at Don Mong, and 17 times in 50 days at Pra Yeun. The soils remained flooded throughout the experimental period. Samples were taken using 10 cm open-ended glass tubes, with an internal diameter of 12 mm. To take a sample, the tube was inserted 2-3 cm into the soil, then withdrawn while holding the thumb over one end (to create suction). This was done four to five times until the tube was full. Each insertion, from different locations within the plot, added about 1.25 cm of soil in the tube. Once filled, both ends of the tube were sealed with rubber stoppers (personal communication from Dr. Buresch at IRRI May 1986)

2.2.6 Assay procedure

The samples were taken to the laboratory for NH_4^+-N determination. Samples that could not be extracted or distilled the same day were refrigerated. Moisture content (100°C for 24 hr) was determined on a subsample of the wet soil. The extracted soil N was expressed on an oven-dried basis (ODB). Ammonium was extracted by shaking the wet soil sample in 100 mL of 2M KCl for 0.5 h, followed by direct steam distillation of the entire soil + KCl(aq) mixture with MgO (Keeney and Nelson, 1982). The extracted NH_4^+ was collected in 2.22% boric acid, and the quantity collected was measured by titrating with 0.01M HCl to pH 4.8 (Keeney and Nelson, 1982).

A random check was made on 3 samples to determine whether or not NO_3^--N was present. After the NH_4^+ distillation step, Devarda's alloy was added to the distillation flask and the sample was redistilled.

2.2.7 Data analysis and Calculations

The calculation for mg NH4+-N kg^{-1} soil (ODB):

$$= \frac{0.01 \text{ Molar HCl*(titrant for sample - titrant for blank)*14 * 1000 g kg}^{-1}}{\text{dry mass of soil sample}}$$

Specific example:

Blank titration = 0.5 mL
Molarity of the titrant = 0.01 mmoles mL^{-1}
Sample titration = 0.75 mL
Soil mass = 6.04 g

$$= \frac{0.01 \text{ mmole mL}^{-1} \text{ HCl*(0.75mL titrated for sample - 0.5mL titrated for blank)*14mg mmole}^{-1}}{\text{6.04g of soil (ODB)}}$$

$$= \frac{0.01\text{*mL titrated * 14mg}}{6.04\text{g}}$$

$$= 0.0058 \text{ mg g}^{-1} * 1000 \text{ g kg}^{-1}$$

$$= 5.8 \text{ mg NH}_4^+\text{-N kg}^{-1} \text{ soil (ODB)}$$

The data for each site (in both years) were analyzed using a nonlinear (exponential) least squares (NLLS) fitting procedure (SAS, 1987). The model fitted to the data was:

$$N_t = N_0 \cdot (1-N_0 \cdot \exp[-k \cdot t]) \qquad [1]$$

where N_t is the amount of ammoniacal N accumulated (mg kg^{-1}) by time *t* (d) out of a finite maximum accumulation (N_0; mg kg^{-1}), and *k* is the rate constant (d^{-1}). This is formally identical to potentially mineralizable N, and refers to mineralizable N, but is restricted to NH_4^+-N accumulation in a flooded soil where NH_3 volatilization is possible (Wani *et al.*, 1990; Griffin and Laine, 1983; Smith *et al.*, 1980).

The adequacy of the exponential model to describe NH_4^+-N accumulation of single treatments at a site was examined by testing the reduction in the residual sum of squares relative to combining two treatments at a time. The null hypothesis (H_0) considered that the model derived by combining treatments was not statistically different at Alpha ≤0.05 from the model derived from the treatments separately. The sum of square residuals of the pooled model and the sum of squares residuals of each separate treatment model were used to calculate the *F*-statistic (Burton and McGill, 1989; Izaurralde *et al.*, 1986):

$$F_{calculated} = ((SS(H_0))/(df\ A - df\ B - df\ C)) \ / \ ((SS(B) + SS(C))/(df\ B + df\ C))$$

where: SSres = SS(B) + SS(C), and $SS(H_0)$ = SS(A) - SSres; and where: SS(A) is the sum of squares residual for the pooled data, SS(B) is the sum of squares residual for one treatment, SS(C) is the sum of squares residual for the second treatment, df is the degrees of freedom for each model. The result was compared to an *F* value at $P \leq 0.05$ with 1 and *n-p* degrees of freedom, where *n* = the number of data points and *p* = the number of parameters.

The values for N_0 and *k* from each model correlate. Comparisons of the different treatments are, therefore, done by using the instantaneous rate of accumulation (Wani *et al.*, 1990). The accumulation rate (mg kg^{-1} d^{-1}) at any time "*t*" is the slope of the plot of N_t against "*t*"; dN_t / dt. This is obtained by differentiating [1] with respect to "*t*", to yield:

$$dN_t / dt = k \cdot N_0 \cdot (\exp[-kt]) \qquad [2]$$

At $t = 0$ this reduces to $N_0 \cdot k$. The choice of $t = 0$ does not require an arbitrary selection of time or quantity of N mineralized (Wani *et al.*, 1990).

2.3 Results

2.3.1 Green Manure Production

The water content of fresh *S. rostrata* green manure averaged 700 g kg^{-1}, and the N content on a dry basis averaged 25.1 g kg^{-1}, irrespective of site. The FGM treatment consistently produced more green manure biomass, and therefore, more N, than the GM treatment (Table 2.1).

2.3.2 Ammonium determination

The decomposition of the N rich green manure resulted in a distinct odor that was noticeable from several hundred meters away.

The field sampling technique, followed by KCl extraction and steam distillation, yielded data that had discernible trends. As the green manure decomposed the concentration of KCl-extractable NH_4^+-N increased to a plateau during the first 5-25 days; with the exception of the DM89 GM and DM89 CTL treatments (Figures 2.1-2.3). This trend was observed irrespective of soil salinity. Each of the three treatments at each site (and in both years) reached unique maxima (or steady states) in the predicted curves (Tables 2.2 and 2.3).

The parameter estimates from the NLLS models fitted to the data from each treatment were significantly different from each other at $P \leq 0.05$. The GM vs FGM at DM89 did not meet the cut off criteria for significance (Tables 2.4 and 2.5).

The proportion of N extracted from the soil that was derived from the *S. rostrata* was usually higher for the FGM treatment than the GM treatment. Ammonium concentrations of the GM treatment were 1.4 to 1.8 times those of the CTL treatment; while those of the FGM treatment were 1.5 to 3.6 times those of the CTL treatment (Table 2.6).

The instantaneous rates of N accumulation for days 0, 1, and 5 were calculated. On day 0, no treatment effects were discernible, but on days 1 and 5 treatment effects were obvious. The magnitude of the N_0 values were smallest for the CTL and largest for the FGM treatments (Table 2.7). Net accumulation of NH_4^+-N was over in about 5 days or shortly thereafter. However, the net accumulation of NH_4^+-N at PYa88 with FGM proceeded for 15 days.

2.4 Discussion

Sesbania rostrata was grown under the prevailing climatic and soil conditions of the Northeast. The growth period varied (58-93 days) due to the requirement for sufficient rain to flood the fields. The longer standing green manure crop supplied more N to the soil than the shorter standing crop. Fertilizing the green manure with 37.5 kg ha^{-1}, both of, K_2O and P_2O_5, resulted in a significant increase in the *S. rostrata* biomass and the N accumulated therein, which was sufficient N to raise NH_4^+-N concentrations in the flooded soil. The long growth period required by the *S. rostrata* green manure crop did not interfere with the timing of rice transplantation. In fact, reduction in rice yields occurs when the determinate varieties used in the Northeast are planted before August. Longer standing rice is more susceptible to lodging and pest infection (Rice Research Station, Department of Agriculture at Khon Kaen, 1990).

In this experiment, *S. rostrata* accumulated N at 104 kg ha^{-1} in 58 days to 267 kg ha^{-1} in 93 days. This was similar to the 148-176 kg ha^{-1} of N accumulated by nonfertilized green manure crops in 40 to 60 days (Morris *et al.*, 1989; Herrera *et al.*, 1988; Baquiravan *et al.*, 1988; Rinaudo *et al.*, 1983). The GM treatment, however, never reached the N accumulations of the FGM treatment, which produced more biomass during the same growth period. The apparent differences in *S. rostrata* green manure biomass production extend to the subsequent concentration of soil NH_4^+-N. The FGM treatment was associated with a higher NH_4^+ concentration than was the GM treatment. But, the GM treatment itself was also significantly greater than the CTL.

Although NO_3^- is a useable form of N, anaerobic soil/water conditions prevent oxidation of NH_4^+ to NO_3^- released from decomposition of green manure (De Datta, 1981). The NO_3^- concentration detected (0.0 to 5.7 mg kg^{-1}) supports the conclusion that NO_3^- is not in the system to be available to rice (Gambrell *et al.*, 1976; Ponnamperuma, 1972). The concentration of NH_4^+ in an incubated soil is, therefore, the best indication of fertility for an ensuing rice crop (Chang, 1978).

Potassium chloride-extractable NH_4^+-N indicates the amount of N available for plant use at the time of sampling. It includes mineral N both in solution and on the exchange complex. This N can readily replace N removed from solution by uptake, immobilization, and various loss mechanisms from the system (Westcott and Mikkelsen, 1987). In this experiment, the concentration of KCl extracted NH_4^+-N rose after incorporation of green manure. Beri *et al.*, 1989, reported that incubating *S. aculeata* resulted in decomposition of 40% of the added carbon within the first two weeks. Similarly, Bhardwaj and Dev (1985), observed rapid mineralization of 97.6-165.1 kg ha^{-1} of N (from 18.2-37.1 Mg ha^{-1} of fresh *S. cannabina*) in the first 63 days after incorporation, most of which was mineralized in the first 21 days. This period of rapid mineralization corresponded to the most active period of rice growth (i.e. establishment and tillering).

As a comparison, El-Garous *et al.* (1990) in a study of soil N mineralization under arid conditions in Morocco (at 17°C), also observed an initial rapid mineralization which declined with time. Both an exponential and a hyperbolic model were fit to the data. The N-mineralization potentials ranged from 120-241 mg kg^{-1}, while the rate constant k ranged from 0.060-0.274 $week^{-1}$. Similarly, Wani *et al.* (1990) observed N mineralization potentials in Orthic Gray Luvisols in Alberta, Canada, which ranged from 204-451 mg kg^{-1}, while the rate constant k ranged from 0.024-0.034 $week^{-1}$. The potential NH_4^+-N accumulation values reported in this experiment are low compared to those of El-Garous *et al.* (1990) and Wani *et al.* (1990) and the rate constants are higher than those reported by others. This experiment, however, was different because it examined the decomposition of tons of green manure in a flooded soil system. Measurements of NH_4^+-N concentrations of other (isohyperthermic) flooded soils in India and The Philippines are comparable to this experiment (Beri *et al.*, 1989; Furoc and Morris, 1989; Nagarajah *et al.*, 1989).

In this experiment, the maximum steady state accumulation of NH_4^+-N occurred within the first two weeks. The N_t values are net values because of concurrent volatilization, and are expected to be less than the actual amount of N mineralized. Recovered mineralized N (N_0 = mg kg^{-1}) ranged from: 6.5-20.5 in the CTL; 9.6-28.4 in the GM; and 16.6-30.8 in the FGM. The instantaneous rates (mg kg^{-1} d^{-1}) for day 1 (chosen rather than day 0 because the treatments were ranked) were: 1.9-3.0 in the CTL; 2.3-4.5 in the GM; and 4.0-8.2 in the FGM.

Bhardwaj and Dev (1985) suggested that rapid mineralization of N may lead to greater losses by volatilization and denitrification, if time is left for decomposition before transplanting the rice crop. DeDatta (1977) reported that loss of added N by NH_3 volatilization in lowland rice soils ranged from 5-47%; while loss by denitrification ranged from 28-33%. Deep placement of fertilizer and a soil with a high CEC help control these losses (Vlek and Craswell, 1979).

It would appear that the high rate constants are a composite function of a volatilization regulated steady state. Volatilization of NH_4^+ is inferred because of the high temperature, flooded conditions, and the type of residue (*i.e.* a N rich green manure as opposed to soil organic matter) (Freney *et al.*, 1981). The differences in the rate constants and N_0 values from different sites and on different soils support the hypothesis that a universal *k* does not exist. Juma *et al.* (1984) suggested that N_0 does not exist as a homogeneous, discrete N component; rather that N in soil is present in various moieties which undergo mineralization at different rates.

Nagarajah *et al.* (1989) suggested that maintenance of a concentration of NH_4^+-N over time after an initial sharp rise, indicates that NH_4^+-N released from green manure is retained in the soil if flooded conditions persist. Nagarajah *et al.* (1989) also observed that the NH_4^+-N concentration dropped in the presence of rice plants and concluded that the drop was primarily the result of plant uptake. Nagarajah *et al.* (1989) assumed that volatilization and denitrification were of little importance because, in the absence of rice plants, the concentration of NH_4^+-N stayed the same or slowly rose. It is not clear, however, that significant losses to volatilization were not occurring, because simultaneous NH_4^+-N generation and loss would also result in a steady state.

In this experiment, a rapid loss of added N was indicated by high rate constants, but low N_0. In addition, there was less N accounted for than was added in the green manure. Recovery of N added in green manure ranged from 5.8-9.6% for FGM, and 7.6-16.4% for GM (Table 2.6). The predicted curves from the NLLS indicated that the concentration of NH_4^+ was maintained at a characteristic value for each site following the initial phase of increasing concentration. Continued mineralization of NH_4^+ following green manure incorporation, if it occurred, must have been balanced by volatilization losses. Nagarajah *et al.* (1989) also concluded that continuous N mineralization occurred because they observed soil solution NH_4^+-N concentrations increased again after rice plants were harvested. Consequently, plant uptake and volatilization exceeded mineralization. Therefore, the presence of plants did not preclude volatilization and mineralization from occurring. The steady state observed in the absence of rice plants (Nagarajah *et al.*, 1989), and the long lasting plateau in this experiment is consistent with mineralization and losses at equal rates. The suggestion by Abrol and Palaniappan, 1988, and Bhardwaj and Dev, 1985, that a lag period before transplanting in the hot tropics was unnecessary is confirmed by these results. It is concluded that, release of N from incorporated green manure in this experiment was sufficiently rapid that rice planted immediately following incorporation of green manure would benefit from the available N at a stage of growth when N supply had the greatest effect on yield and before losses removed the N from the plant environment.

Under saline soil conditions (1.5-6 dS m^{-1}) N uptake by rice plants is inhibited (Broadbent *et al.*, 1988). Moreover, as NaCl concentrations increase the solubility of $NH_{3(g)}$ decreases. Therefore, except for deeply placed N fertilizers, volatilization losses rise as salt concentrations increase (Sen and Bandyopadhyay, 1987). No relationship between salinity and NH_4^+ concentrations was discernible in this experiment. Ammonium concentrations at the saline site, as at the non-saline site, appeared to be a function of the amount of green manure incorporated.

2.5 Conclusion

It is concluded that on fine loamy to coarse loamy isohyperthermic Ultisols and Alfisols in Northeast Thailand, the incorporation of *S. rostrata*:

1. raised NH_4^+-N accumulation in direct proportion to the amount of biomass incorporated such that: *S. rostrata* fertilized with 37.5 kg ha^{-1} of both P_2O_5 and K_2O was ~2.8 times greater than the control, and unfertilized *S. rostrata* was ~1.6 times the control - more *S. rostrata* meant more biologically fixed N and ultimately greater NH_4^+-N concentrations;

2. raised NH_4^+-N accumulations irrespective of high salinity (12 dS m^{-1});

3. produced characteristically low values for NH_4^+-N accumulation (N_0) and high rate constants (*k*), suggesting a steady state, from which it is inferred that losses by volatilization and denitrification kept pace with mineralization, and;

4. because NH_4^+-N accumulation started soon after ploughing down the *S. rostrata*, immediate transplanting of rice would be critical to maximize N use by the rice crop.

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TABLE 2.1 Yield of *S. rostrata* green manure, including both above ground parts and the cleaned roots. The water content of the green manure was 700 g kg^{-1}.

Site	Year	Treatment	Growth days	Yield Wet Mg ha^{-1}	St. dev.	N equivalent kg ha^{-1}
DM	1988	FGM	93	35.5	4.4	267
		GM	93	6.9	2.1	52
DM	1989	FGM	78	23.1	10.4	174
		GM	78	10.5	8.0	79
PYa	1988	FGM	89	30.5	3.2	229
		GM	89	11.3	2.3	85
PYa	1989	FGM	58	13.8	3.1	104
		GM	58	2.4	0.8	18

St. dev. = standard deviation

TABLE 2.2 Parameter Estimates from the nonlinear least squares analysis (NNLS) for the nonsaline DM88 and DM89 sites. The maximum accumulation of NH_4^+-N is N_0 (mg kg^{-1}), and *k* is the rate constant (d^{-1}).

	Parameter estimates					Nonlinear Least Squares Summary			
Year/ Site	TRMT	N_0	SE	k	SE	Source	df	S. Squares	R^2
DM88	CTL	9.0	0.7	1.52	1.45	Regr	2	6,605	0.69
						Res	82	2,982	
						Total	84	9,588	
	GM	16.2	0.8	0.43	0.12	Regr	2	19,222	0.87
						Res	82	2,975	
						Total	84	22,198	
	FGM	30.8	1.8	0.40	0.14	Regr	2	69,137	0.81
						Res	82	16,213	
						Total	84	85,350	
DM89	CTL	20.5	1.4	0.10	0.02	Regr	2	20,965	0.84
						Res	86	3,996	
						Total	88	24,961	
	GM	28.4	2.2	0.11	0.02	Regr	2	42,397	0.80
						Res	86	10,896	
						Total	88	53,293	
	FGM	30.6	2.3	0.15	0.04	Regr	2	56,672	0.78
						Res	86	16,084	
						Total	88	72,757	

TABLE 2.3 Parameter Estimates from the nonlinear least squares analysis (NNLS) for the saline (*i.e.* 12 dS m^{-1}) PYa88 and PYa89 sites. The maximum accumulation of NH_4^+-N is N_0 (mg kg^{-1}), and *k* is the rate constant (d^{-1}).

Parameter estimates						Nonlinear Least Squares Summary			
Year/ Site	TRMT	N_0	SE	k	SE	Source	df	S. Squares	R^2
PY88a	CTL	8.0	0.4	0.69	0.31	Regr	2	5,349	0.81
						Res	88	1,284	
						Total	90	6,633	
	GM	14.5	1.0	0.47	0.2	Regr	2	16,747	0.76
						Res	88	5,185	
						Total	90	21,932	
	FGM	29.0	2.0	0.30	0.1	Regr	2	63,147	0.77
						Res	89	18,811	
						Total	91	81,959	
PY89a	CTL	6.5	0.6	0.81	0.53	Regr	2	2,495	0.69
						Res	62	1,116	
						Total	64	3,611	
	GM	9.6	0.8	0.34	0.14	Regr	2	4,490	0.76
						Res	59	1,388	
						Total	64	5,879	
	FGM	16.6	1.3	0.38	0.15	Regr	2	14,759	0.78
						Res	63	4,229	
						Total	65	18,988	

TABLE 2.4 Comparison of GM, FGM, and the CTL at DM88 and DM89. To determine the statistical siginificance of the treatments, the data sets of two treatments were combined and a model fitted to the data. The hypothesis was that the model derived by combining the treatments was not different at Alpha ≤ 0.05 from the model derived using the treatments separately.

Site/Year Comparison	Source	Sum of Squares	df	Fc	R^2
DM88					
GM vs FGM	(H_0)res	26,915	166		0.75
	GMres	2,975	82		0.87
	FGMres	16,213	82		0.81
	(H_a)res	19,189	164		
	(H_0)	7,725	2	33.0*	
CTL vs GM	(H_0)res	7,747	166		0.76
	CTLres	2,982	82		0.69
	GMres	2,975	82		0.87
	(H_a)res	5,958	164		
	(H_0)	1,788	2	24.6*	
CTL vs FGM	(H_0)res	36,232	166		0.62
	CTLres	2,982	82		0.69
	FGMres	16,213	82		0.81
	(H_a)res	19,196	164		
	(H_0)	17,035	2	72.8*	
DM89					
GM vs FGM	(H_0)res	27,629	174		0.78
	GMres	10,896	86		0.80
	FGMres	16,084	86		0.78
	(H_a)res	26,980	172		
	(H_0)	648	2	2.1	
CTL vs GM	(H_0)res	16,772	174		0.78
	CTLres	3,996	86		0.84
	GMres	10,896	86		0.80
	(H_a)res	14,892	172		
	(H_0)	1,879	2	10.8*	
CTL vs FGM	(H_0)res	24,611	174		0.75
	CTLres	3,996	86		0.84
	FGMres	16,084	86		0.78
	(H_a)res	20,081	172		
	(H_0)	4,529	2	19.4*	

(H_0)res = sum of squares residual under H_0
CTLres = sum of squares residual for treatment CTL
GMres = sum squares residual for treatment GM
FGMres = sum of squares residual for treatment FGM
(H_a)res = sum of squares residual under H_a
(H_0) = sum of squares due to deviations from H_0

$$Fc = [(H_0)/df(H_0)] \,/\, [(H_a)res/\, df(H_a)res]$$

* indicates significance at alpha = 0.05

TABLE 2.5 Comparison of GM, FGM, and the CTL at PYa88 and PYa89. To determine the statistical siginificance of the treatments, the data sets of two treatments were combined and a model fitted to the data. The hypothesis was that the model derived by combining the treatments was not different at Alpha ≤ 0.05 from the model derived using the treatments separately.

Site/Year Comparison	Source	Sum of Squares	df	Fc	R^2
PYa88					
GM vs FGM	(H_0)res	31,368	179		0.70
	GMres	5,185	88		0.76
	FGMres	18,811	89		0.77
	(H_a)res	23,997	177		
	(H_0)	7,370	2	27.2*	
CTL vs GM	(H_0)res	8,082	178		0.72
	CTLres	1,284	88		0.81
	GMres	5,185	88		0.76
	(H_a)res	6,469	176		
	(H_0)	1,612	2	21.9*	
CTL vs FGM	(H_0)res	36,072	179		0.59
	CTLres	1,284	89		0.81
	FGMres	18,811	88		0.77
	(H_a)res	20,096	177		
	(H_0)	15,975	2	70.4*	
PYa89					
GM vs FGM	(H_0)res	6,926	124		0.72
	GMres	1,388	63		0.76
	FGMres	4,229	59		0.78
	(H_a)res	5,618	122		
	(H_0)	1,307	2	14.2*	
CTL vs GM	(H_0)res	2,713	123		0.71
	CTLres	1,116	62		0.69
	GMres	1,388	59		0.76
	(H_a)res	2,505	121		
	(H_0)	207	2	5.0*	
CTL vs FGM	(H_0)res	7,913	127		0.65
	CTLres	1,116	63		0.69
	FGMres	4,229	62		0.78
	(H_a)res	5,345	125		
	(H_0)	2,567	2	30.0*	

(H_0)res = sum of squares residual under H_0
CTLres = sum of squares residual for treatment CTL
GMres = sum squares residual for treatment GM
FGMres = sum of squares residual for treatment FGM
(H_a)res = sum of squares residual under H_a
(H_0) = sum of squares due to deviations from H_0

$$Fc = [(H_0)/df(H_0)] \;/\; [(H_a)res/\ df(H_a)res]$$

* indicates significance at alpha = 0.05

Table 2.6 The proportion of N from the green manure extracted as NH_4^+.

Site+ Year	Treatment	N_0 mg kg^{-1}	(N_0 TRMT - N_0 CTL) mg kg^{-1}	% recovery**
DM88	FGM	30.8	21.4	8.0
	GM	16.2	7.0	13.6
	CTL	9.0	-	
DM89	FGM	30.6	10.0	5.8
	GM	28.4	8.0	10.1
	CTL	20.5	-	
PYa88	FGM	29.0	21.0	9.2
	GM	14.5	6.5	7.6
	CTL	8.0	-	
PYa89	FGM	16.6	10.0	9.6
	GM	9.6	3.0	16.4
	CTL	6.5	-	

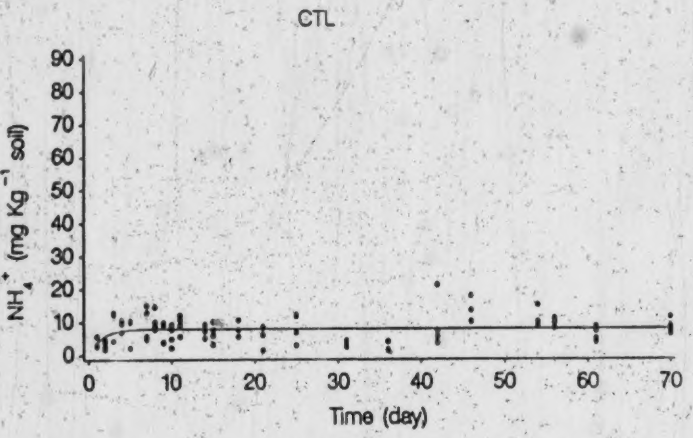
**% recovery from green manure =

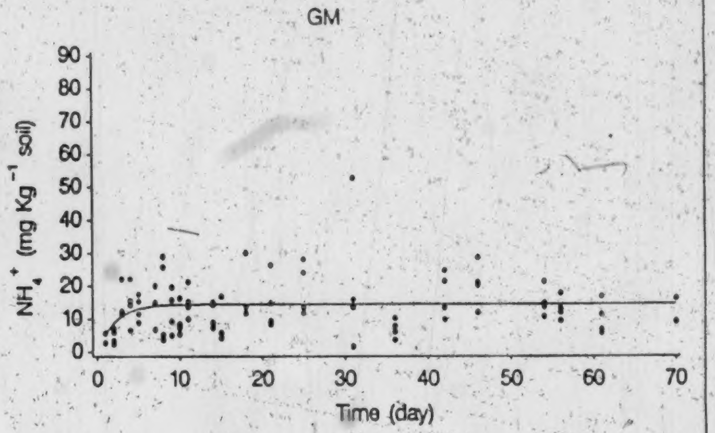
$$\frac{100 * (N_0 \text{ TRMT mg kg}^{-1} - N_0 \text{ CTL mg kg}^{-1}) * 1{,}000{,}000 \text{ kg soil ha}^{-1}}{\text{kg Nitrogen added ha}^{-1}}$$

TABLE 2.7 - Instantaneous Rate of Mineralization (mg kg^{-1}).

		MINERALIZATION RATES PARAMETER ESTIMATES		INSTANTANEOUS RATE (mg kg^{-1} d^{-1})* AT DAY:		
YEAR/SITE	TRMT	N_0	k (day^{-1})	0	1	5
	CTL	9.0	1.52	13.6	3.0	0.0
DM88	GM	16.2	0.43	6.9	4.5	0.8
	FGM	30.8	0.40	12.3	8.3	1.7
	CTL	20.5	0.10	2.1	1.9	1.2
DM89	GM	28.4	0.11	3.1	2.8	1.8
	FGM	30.6	0.15	4.6	4.0	2.2
	CTL	8.0	0.69	5.5	2.8	0.2
PY88a	GM	14.5	0.47	6.8	4.2	0.7
	FGM	29.0	0.30	8.7	6.4	1.9
	CTL	6.5	0.81	5.3	2.3	0.1
PY89a	GM	9.6	0.34	3.3	2.3	0.6
	FGM	16.6	0.38	6.3	4.3	0.9

* $dN_t/dt = k \cdot N_0 \cdot (\exp{-kt})$





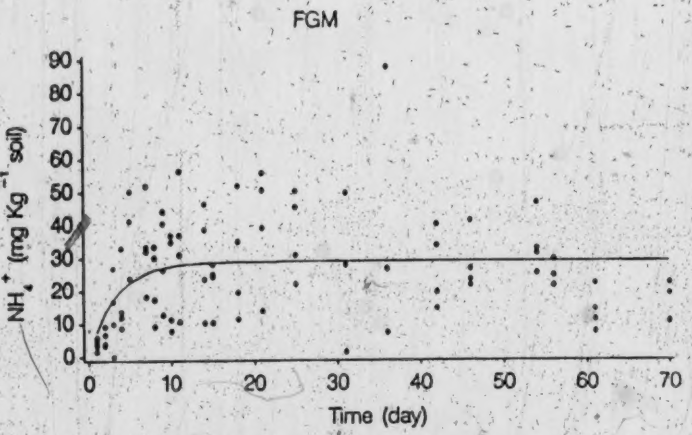


FIGURE 2.1 Data array for KCl extracted NH_4^+-N from the control (CTL) plots at the saline site PYa88 with the predicted curve superimposed

FIGURE 2.2 Data array for KCl extracted NH_4^+-N from the fertilized *S. rostrata* (FGM) plots at the saline site PYa88 with the predicted curve superimposed

FIGURE 2.3 Data array for KCl extracted NH_4^+-N from the nonfertilized *S. rostrata* (GM) plots at the saline site PYa88 with the predicted curve superimposed

CHAPTER 3 THE FATE OF N FROM GREEN MANURE (SESBANIA ROSTRATA) ADDED TO RICE GROWN ON SANDY, SALINE SOILS IN NORTHEAST THAILAND

3.1 Introduction

Green manuring, the practise of incorporating easily decomposable (usually leguminous) plant material into agricultural lands, is a means of supplying nutrients to crops growing on N deficient soils. The practise has been used successfully to reclaim derelict land (Jefferies et al, 1981). The efficiency with which fertilizer or green manure is used by plants is called fertilizer-use-efficiency (F-U-E). F-U-E can be viewed from two perspectives. In the first, the yield and economic return are calculated by the traditional Difference Method. This accounts for the N yield of a crop (i.e. in the straw and grain) grown with fertilizer compared to the N yield of a control (Westerman and Kurtz, 1974; Nagarajah et al., 1989), but also integrates non-nutritional contributions. In the second method, the fate of the added N fertilizer, (calculated by the Isotopic Method) accounts for N added regardless of its chemical forms. This is because the ^{15}N isotope in the system comes from labelled fertilizer, and behaviour of labelled fertilizer N is the same as fertilizer N with a natural abundance of ^{15}N (Edwards, 1977). The purpose in using ^{15}N labelled fertilizer is to distinguish between N derived from soil or from fertilizer (Jenkinson *et al.*, 1985). In this experiment, green manure was labelled to distinguish between N derived from green manure and soil-derived N.

The research reported here extends the scope of the work documented in Chapter 2, by monitoring yield potentials of green manured rice crops and the fate of N from *S. rostrata* ploughed down before growth of a rice crop. This research had four premises: (1) P and K fertilization improves biomass production of *S. rostrata* and the subsequent mass of N incorporated into the soil, and conversely, that yields of rice do not increase with direct applications of P and K fertilizer; (2) yield increases can be adequately measured by measuring % filled spikelets, tiller number, grain mass, straw mass, and the mass of N in the harvested grain and straw; (3) ^{15}N from a mineral source is incorporated into the *S. rostrata* even though it fixes large quantities of N; and, (4) the *S. rostrata* green manure is sufficiently labelled (with ^{15}N) to label the subsequent rice crop after green manure incorporation.

The following hypotheses were tested: 1) N is released through decomposition and N mineralization of P and K fertilized green manure; and, 2) this N is subsequently incorporated into the rice crop to increase grain and straw yields, and therefore, the N yield of the crop. A further objective was to discover the fate of N from the green manure in the soil-plant system.

3.2 Materials and Methods

3.2.1 Sites

Soil and climatic conditions at the Don Mong 1988 (DM88), Don Mong 1989 (DM89), and Pra Yeun 1988 (PYa88) sites were described in Chapter 2.

The Pra Yeun 1989 (PYb89) site is on a middle terrace with a 2-3% slope. Flooding occurs annually to a maximum depth of 10 cm for 1-2 months. The soil is a fine-loamy, siliceous, isohyperthermic Oxic Paleustult (USDA Soil Taxonomy). The Ap horizon (0-25 cm) has a pH of 5.5, total N = 0.2 g kg^{-1}, P = 49 mg kg^{-1}, and ECe = 0.5 dS m^{-1}.

3.2.2 Experimental Design - the Yield Experiment

In 1988, the experimental design was a 3 x 2 factorial with three replications in a completely randomized design. In 1989, the design was changed to a randomized complete block (3 blocks). The first three treatments included: (1) *S. rostrata* plus 37.5 kg ha^{-1} of both P_2O_5 and K_2O (FGM); (2) *S. rostrata* without fertilizer (GM); and (3) Control (no *S. rostrata* and no fertilizer) (CTL). The second two treatments after rice transplantation included either 37.5 kg ha^{-1} of both P_2O_5 and K_2O with the transplanted rice, or rice with no further amendments.

3.2.2.1 Cropping Procedure

Sesbania rostrata seed was soaked in water outdoors for two days to break dormancy and was broadcast onto the plots at 30 kg ha^{-1}. The seeding date depended upon adequate rainfall and varied between sites and years (Table 3.1). When the plants reached 10-20 cm in height, fertilizer was broadcast onto designated plots.

When the plants reached 1.5-2.0 m in height and soils were flooded to 5-10 cm (Table 3.1), the *S. rostrata* in each plot was uprooted, washed, and weighed, and incorporated as green manure. (Fertilized *S. rostrata* contributed an average N equivalent of 104.8 kg ha^{-1}, while nonfertilized *S. rostrata* contributed an average of 76.4 kg ha^{-1}.) Incorporation, by hoeing, was facilitated by chopping the *S. rostrata* into 15 cm lengths and trampling it underfoot. The aim was to incorporate the *S. rostrata* green manure in the reduced layer to reduce N losses to volatilization, because surface applications are subject to high losses (DeDatta, 1987; Mikkelsen, 1987; Sen and Bandyopadhyay, 1987). A sample of the *S. rostrata* green manure was taken for analysis of moisture content and total N. The soils remained flooded throughout the experimental period, except at PYb-89, where coarse soil texture allowed extensive leaching.

Rice (~30 days old) was transplanted at 4-7 seedlings *per* hill immediately after the *S. rostrata* green manure was ploughed in. Hill spacing varied (13.8-19.4 hills m^{-2}), but the variation was accounted for by including hill spacing as a covariate during analysis of variance.

3.2.2.2 Residual Experiment

In 1989, a complementary experiment was devised to determine if residual effects of *S. rostrata* green manuring from 1988 could be detected in 1989. The **Residual Experiment** was run on the DM88 and PYa88 sites; designated by R-DM89 and R-PYa89. The land was ploughed and harrowed prior to tranplanting. Planting was performed as described in 3.2.2.1.

3.2.2.3 Yield components

At all sites in both years, harvesting commenced in mid-November to early December. The yield components measured were: 1) the number of tillers in ten randomly selected hills; 2) the grain mass for each plot; 3) the straw mass for each plot; 4) the number of full and empty spikelets *per* random sample from each plot (% Filling); 5) the mass of 100 filled spikelets; and, 6) the total N concentration in the grain and straw.

3.2.2.4 Nitrogen analysis

Three replicates of finely ground grain and straw samples, each of ~0.5 to 0.9 g, were digested in H_2SO_4 (~18M) with ~1.0 g of potassium sulphate catalyst mixture (200 g K_2SO_4, 20 g $CuSO_4 \cdot 5H_2O$, and 2 g Se) at 400°C for five hours. The digested samples were cooled, and distilled water was added. When cool, the diluted samples were filtered into 100 mL volumetric flasks. Samples of 40 mL were distilled with NaOH (~10 M), and the NH_4^+ collected in ~2% boric acid. The quantity collected was measured by titrating with 0.01M HCl to pH 4.8 (Bremner and Mulvaney, 1982).

3.2.2.5 Statistical analysis

Analysis of variance (proc GLM on SAS) was used to compare means of the following yields: straw (Mg ha^{-1}); percent N content of straw; N yield in straw (kg ha^{-1}); grain yield (Mg ha^{-1}); N content of grain (%); N yield in grain (kg ha^{-1}); the number of tillers *per* hill; the percent fill; and the mass of 100 full spikelets.

The number of hills m^{-2} was used as a covariate for all sites. Salinity was also used as a covariate for the saline PYa88 and R-PYa89 sites. Alpha equalled 0.05 for all analyses.

3.2.3 Experimental Design - the ^{15}N Experiment

3.2.3.1 Growth of ^{15}N labelled *S. rostrata*

1988

Plastic buckets (4 @ 15 cm radius x 38 cm high) were filled with Ap horizon from a fine loamy siliceous isohyperthermic Oxic Paleustult (not from the study sites) with an initial total N content of 0.37 g kg^{-1}. Two buckets containing ~23 kg of soil each received 17.65 g of $(NH_4)_2SO_4$ (^{15}N 5.3 atom %). Two other buckets each received 47.70 g, but the resultant salt concentration in the soil killed the *S. rostrata* seedlings. Seed dormancy of *S. rostrata* was broken by soaking seeds in H_2SO_4 (18M) for 30 minutes and thoroughly rinsing in water. Ten seeds were sown in each bucket. The *S. rostrata* was not inoculated so that the plant would draw all of its N from the soil.

1989

The labelled soil from the 1988 experiment was mixed with the same amount of nonlabelled soil so that seven plastic buckets (15 cm radius x 38 cm high) were filled. The atom %Ab. ^{15}N in the soil was 0.658%. To break seed dormancy, seeds of *S. rostrata* were soaked in water overnight, and then sown in the buckets.

In both years 37.5 kg ha^{-1} of both P_2O_5 and K_2O were added (Starter rate for legumes recommended by the Department of Land Development).

3.2.3.2 Green Manure Incorporation and Rice Transplantation

After several weeks growth the *S. rostrata* was uprooted, washed, chopped, and incorporated into six open-ended buckets inserted into Yield Experiment plots (DM88). The lip of the bucket stood 8 cm above the soil surface to prevent loss of the added green manure. The non-glutinous determinate tall Thai rice "KDM-105" was planted at 8 plants *per* bucket at Don Mong. The glutinous determinate tall Thai rice "KD-6" was planted at 8-10 plants *per* bucket at Pra Yeun.

Moisture content, total N, and atom % Ab. ^{15}N were determined on sub-samples of the green manure. In 1989, the experiment was repeated at DM89 and PYb89.

3.2.3.3 Site Conditions After Rice Transplantation

The greatest losses of added N occur during frequent episodes of wetting and drying (Patrick and Wyatt, 1964; Reddy and Patrick, 1975; Smith and Patrick, 1983). Thus, a decision was made in this experiment to maintain flooded soils where possible. At Don Mong, flooding level was between 2-10 cm for the first 70 days after transplantation in 1988, but only for 60 days in 1989. At Pra Yeun, the

Pra Yeun, the soil was flooded for only the first month because rainfall was inadequate to compensate for evaporation and leaching from the sandy soil.

3.2.2.4 Nitrogen analysis

Total N content and ^{15}N atom % abundance (%Ab.) in finely powdered plant samples were determined using a Carlo Erba NA-1500 Nitrogen Carbon Sulphur Analyzer and a Micromass triple collector mass spectrometer (SIRA, Series II, VG Isogas, Cheshire, England) connected by a continuous flow interface. The background values used to convert ^{15}N %Ab. to ^{15}N %Ex. were measured on non-labelled materials and were: 0.366 for the *S. rostrata* samples, 0.371 for rice components, and 0.366 for the soil samples.

3.2.3.5 Yield conversion

After harvest of all plants in the bucket, yield components (*i.e.* straw and grain) were determined, and a subsample dried at 70°C for twelve hours to determine moisture content. In 1988, these yield measurements were taken from larger plots with the same fertilizer treatments (*i.e.* rice grown on P and K fertilized *S. rostrata* green manure), as previously described (Section 3.2.1). In 1989, the total straw and grain yields were recorded for each bucket at harvest.

3.2.3.6 Statistical Analysis

The mean and standard deviation (St. dev.) of the % total N and ^{15}N % Ex. are based on six buckets *per* site.

3.2.4 Calculations

1. Mg ha^{-1} = (kg of component m^{-2}) * (10000 m^2 ha^{-1}) * (1Mg 1000 kg^{-1})

2. ^{15}N % Ex. =

(atom % N^{15} Abundance of the labelled material) - (natural atom % N^{15} Abundance)

3. N kg ha^{-1} (dry) = (wet mass kg / ha) (1-(%H_2O/100)) (%N/100)

4. Percent nitrogen derived from green manure (%NdfGM) =

100 * (%Ex. ^{15}N in component / %Ex. ^{15}N in labelled S. rostrata)

5. Percent recovery from green manure (%RNfGM) =

%NdfGM * ((mass of N in component) / (mass of N added in S. rostrata))

6. F.U.E. (Difference Method) =

100 * ((mass of N in treated component) - (mass of N in control)) / total N added in S. rostrata

7. SEM = sqrt (MSE from ANOVA) / sqrt (number of replications)

3.3 Results

3.3.1 Yield Experiment

The premises set out in the introduction were fulfilled. Growth of *S. rostrata* was enhanced when it received an uninterrupted water supply on loamy soil with salinity less than 4 dS m^{-1}. Incorporation of non P and K fertilized *S. rostrata* increased rice yield potential on sandy, saline (12 dS m^{-1}) soils, whereas P and K fertilized *S. rostrata* inhibited biomass production so that there could be no benefit to the subsequent rice crop. Directly fertilizing the rice with P and K had no measureable effect. Green manuring did not significantly alter the % filled spikelets, tiller number, and grain mass of the FGM, GM, and compared to the CTL. *Sesbania rostrata* provided a source of N that was taken up by the subsequent rice crop, demonstrated by the fact that ^{15}N from the labelled green manure was found in the subsequent rice crop.

3.3.1.1 Response of rice to N in green manure

Rice transplanted into the green manured plots was yellow for the first two weeks, more so than rice planted in control plots. In the following weeks, however, rice in the green manured plots was greener than in the control plots. This was especially true for rice growing on fertilized *S. rostrata*.

Total yields of both grain and straw, and the N yield from the grain and straw at Don Mong are presented in Table 3.2. In 1988 at DM88, rice that did not receive *S. rostrata* green manure had the lowest yields. Rice planted into nonfertilized green manure (GM) yielded 1.5 times more grain than the non-amended plots. The fertilized green manure (FGM) plots produced 2.5 times more grain than the non-amended plots (CTL). In 1989 at DM89, an early harvest pre-empted panicle filling, and consequently, did not achieve a statistically significant increase in grain yield, although rice straw yields were highest following the FGM treatment. Straw production on the FGM plots was greater than on the GM plots or the CTL plots, in both years. Taking into account the N yield of the straw components, the FGM produced the greatest response, while GM alone was not significantly greater than the CTL.

The yield pattern observed for rice at the PYa88 experimental site was such that more *S. rostrata* led to greater rice yield (Table 3.3). But P and K fertilization did not increase *S. rostrata* yields, perhaps because the fertilizer increased salinity. Electrical conductivity was 20.8±8.1 dS m^{-1} for the GM plots; 22.0±20.7 dS m^{-1} for the FGM plots; and, 17.2±10.2 dS m^{-1} for the CTL plots. Rice yields may have declined due to salinity in general.

Despite frequent precipitation, the sandy soil at the non-saline site, PYb89, did not retain moisture, so cycles of wetting and drying occurred. Treatment differences were marginally significant (alpha = 0.06) (Table 3.4). Therefore, existing evidence does not permit the conclusion that *S. rostrata* improved rice yields on droughty soils.

3.3.1.3 The Residual Experiment - Effect of 1988 Treatments on 1989 Rice Yields

The results of both R-DM89 and R-PYa89 indicate no carryover effect of green manuring from one year to another. The means for rice yields in 1989 were not significantly different despite the significant treatment effect observed the previous year (Table 3.2 and 3.3).

3.3.1.4 Response of other yield components to N from green manure

Other yield components (mass of 100 Grains, the Percent Filled Spikelets, Tiller number) varied among sites and years, but not among green manure treatments (Table 3.6). Grain mass and % filled spikelets, though often consistent within a year and site, varied between sites and years. The mass of 100 Grains averaged 3.0 g for all sites. Green manuring had little effect on the mass of a filled rice seed. The Percent Filled Spikelets (or seeds), was commonly 85% on the nonsaline sites (DM88, R-DM89, and PYb89), but at PYa88 it was ~61%, some 30% less than non-saline sites, and at R-PYa89 it was 21.3%, again some 30% less than the year before. It would appear that green manuring was associated with a greater number of fertile spikelets, but further research is required to confirm that it is a green manure effect and not variable salinity or moisture. Prolific tillering is indicative of a N rich environment, and should have been a useful indicator of the success of green manuring. But differences in tillering reached statistical significance only at the DM88 site (the FGM and GM treatments had more tillers than the CTL treatment).

3.3.2 ^{15}N Experiment

In both years, *S. rostrata* was labelled with ^{15}N either from the fertilizer or residual ^{15}N in the soil. Labelling of the *S. rostrata* green manure was facilitated by excluding rhizobial inoculum and the low N content of the soil in the labelling pots (0.37 g kg^{-1} total N St. dev. = 0.01). The quantity and characteristics of *S. rostrata* incorporated into buckets, or into field plots are presented in Table 3.6.

The dry matter, N yield, and %NDfGM of rice grown in buckets are presented in Table 3.7. In both years and at both sites, the rice grain and straw were highly labelled from the incorporated *S. rostrata* green manure. The % N derived from green manure (%NdfGM) was at least 33% for every plant component. Despite discontinuous flooding, it is remarkable that ^{15}N uptake at PYb89 was in the same range as DM88 and DM89. The recovery of N from *S. rostrata* labelled with ^{15}N and incorporated into buckets (%RNfGM) ranged from 5.9% to 8.1% in the grain, and 3.0% to 6.7% in the straw (Table 3.8).

Nitrogen use efficiency calculated by the Difference Method ranged from: 4.7% to 9.8% in the grain, and 5.5% to 17.6% in the straw. The N yield increase following *S. rostrata* incorporation was equivalent to 14.4% to 27.4% of the N added as *S. rostrata* (Tables 3.9 and 3.10). In all cases pool substitution is indicated because results with the Isotopic Method are lower than the Difference Method.

3.4 Discussion

The effectiveness of P and K fertilization to improve biomass accumulation by *S. rostrata* depended upon whether or not the soil was saline. At both nonsaline sites (DM88 and DM89), *S. rostrata* that received P and K fertilizer accumulated more biomass than did the nonfertilized *S. rostrata*. At the saline site, PYa88, the response of *S. rostrata* to fertilizer appeared to be inhibited by high salinity. In fact, it was the nonfertilized *S. rostrata* that produced the greatest biomass. It may have been that the addition of triple superphosphate and potash (*i.e.* salts) exceeded the salinity tolerance of *S. rostrata*, and suppressed growth. Therefore, no advantage was observed for P and K fertilization of the green manure on the saline (*i.e.* 12 dS m^{-1}) soils used in this experiment.

The length of the growing period for *S. rostrata* green manure varies according to location (Rinaudo *et al.*, 1983). In The Philippines, 40-60 day old *S. rostrata* contained 100-176 kg nitrogen ha^{-1}. In Senegal, the original niche of *S. rostrata*, a 52 day old crop accumulated 267 kg of nitrogen ha^{-1} (Rinaudo *et al.*, 1983). In contrast, Ranvir *et al.*, 1988 reported that in India 45-60 day old crops accumulated only 60 to 90 kg nitrogen ha^{-1}. Accumulations of N similar to those reported in the Philippines were achieved in this study by seeding with the first rains in mid-May (before flooding, so that the seedlings become established). Incorporation was performed after the *S. rostrata* crop reached 1.5 m. To facilitate ploughing the and to stop re-emergence of the *S. rostrata* the fields needed to be flooded to 10 cm. To meet these conditions a longer growth period (~80 days) was required in both years and at both sites than was reported in other countries. Although future refinements may be necessary, this study demonstrated that: *S. rostrata* can accumulate 150 kg N under non-saline conditions when fertilized with P and K, and 107 kg N under saline conditions without fertilizer, and adequate water.

Rice grain yields, total dry matter yield, N uptake and productive tillers of rice in the Philippines were markedly affected by *S. aculeata*, *S. cannabina*, and *S. rostrata* green manures (Centeno et al., 1985; Furoc and Morris, 1989; Morris et al., 1989; Mulongoy, 1986). In this experiment, rice yields increased significantly when fertilized, *S. rostrata* green manure was incorporated into the soil. The clearest indication of an increase in rice (grain and straw) yields was at DM88, where both the grain and straw yields increased. The mass of N removed in the grain and straw of rice from fertilized *S. rostrata* green manure (FGM) plots, were greater than that of the nonfertilized green manure (GM) plots, which in turn were greater than that of the control (CTL) plots. Even at DM89, where there was no statistically significant increase in grain yields, straw yields from FGM plots were greater than in the CTL, and the N accumulated therein was greater than in the GM plots or the CTL.

The results of the residual (R) effect experiment at R-DM89 strongly support the positive effect observed on FGM plots over GM plots observed in DM88. Although there was no residual effect, the value of this supplemental experiment confirmed that without green manure (either fertilized or nonfertilized) rice yields were no greater than the CTL. If these soils could retain organic N, a residual effect might develop over 3-10 years of green manuring due to remineralization of organic N. The extent of such accumulations may be small due to the high temperatures and sandy soils. Further research is required into organic N accumulations, and mechanisms to enhance retention by soil, of N from *S. rostrata* that is not used by the crop in the current year.

No positive effects of green manuring were observed at the sandy (73%), nonsaline, PYb89 site. The poor result was possibly due to the rapid leaching of rain water, and the low biomass of incorporated *S. rostrata*. Frequent wetting and drying cycles occurred after the green manure was incorporated: conditions noted for extensive N loss, and confirmed by the low recovery of N in the soil (Table 3.8).

The grain/straw ratios from DM88 and DM89 were very low. Evidently, green manure addition to a loamy soil with an ample water supply most significantly affects straw production. There was also some doubt that the crop had completely matured. At PYb89, grain/straw ratios were higher, and water was in short supply.

It is difficult to assess or to verify the changes in rice yields under saline conditions because the effects of salinity were confounded by drought. Nevertheless, the yield of rice straw was enhanced on the GM plots, at the saline (12 dS m^{-1}) PYa88 site, while the CTL and the FGM plots had similar straw yields. This straw yield pattern reflected the greater biomass of *S. rostrata* added to the GM plots.

Abrol and Palaniappan (1988) concluded that green manure fertilized with rock phosphate enhanced rice yields, more than did P applied directly to the rice. In this study addition of P and K fertilizer shortly after transplantation, irrespective of soil texture or degree of salinity, gave no significant benefit to FGM, GM, or CTL plots. The rationale for including this treatment was to discern whether or not P and K fertilization was the agent responsible for improving rice yield potential. However, the P and K fertilization gave greater *S. rostrata* biomass production, which resulted in greater N upon decomposition for the subsequent rice crop.

Thus, the yield response of rice depended on the amount of N added in the green manure. Comparably, the yield response of rice to commercial fertilizer rose as the rate increased. Patrick *et al.*, (1974) observed that chemical fertilizer additions (*i.e.* in the range of 56-112 kg of nitrogen ha^{-1}) improved rice yields: such that (by the Difference Method) a yield benefit of as much as ~40% could be achieved, while the recovery of N by the Isotopic Method (*i.e.* %NRfGM) in the rice and straw ranged from only 17-23%. Similarly, Patrick and Reddy (1976) observed the recovery of added $^{15}(NH_4)_2SO_4$-N ranged from 30.9-37.3% in the grain; 18.2-24.2% in the straw; and 24-27% in the soil. Although the yield benefit from added fertilizer was indisputable in this and other experiments, the Isotopic data indicated that some of the N was immobilized by soil microbes in place of native soil N. Labelled N proxied for nonlabelled N during immobilization - pool substitution as *per* Jenkinson *et al.*, (1985). In this experiment, the proportion of N in rice plants that originates from labelled *S. rostrata* green manure (%NdfGM Table 3.7) was consistently ≥33%. The overall F-U-E or recovery of added N (%RNfGM Table 3.8) for the aboveground portions was only ~11-13% for both sites in both years. Similarly, Chapman and Myers (1987) found that ~11% of the N in the residues of *S. cannabina* were recovered in the above ground portion of the following rice crop. The yield benefit in this experiment, as calculated by the Difference Method, was in the range of 14-27%, not as much as the ~40% reported for chemical fertilizers. However, recovery of N delivered in green manure is often less than that from chemical fertilizers because not all green manure N is mineralized and some N remains in the soil (Bouldin, 1988).

The N recovery in this experiment compared favourably to results from work done in upland crops (Moore, 1974; Ladd *et al.*, 1981; Ladd *et al.*, 1983), except that the proportion of N in the rice from *S. rostrata* green manure was higher (>30%).

In DM88 and DM89, where the flooded condition was maintained, the %RNfGM in the soil ranged from 35.1 to 39.9%. In contrast, at PYb89, where soil flooding was discontinuous, the %RNfGM was only 11.0. The low concentration of ^{15}N detected in the soil after the rice harvest leads to the conclusion that a large proportion of N was lost to denitrification or leaching during the growing season. The highest concentration of residual ^{15}N at DM89 may be due to the fact that DM89 received the largest green manure addition. The proportion of ^{15}N remaining in the soil at PYb89 was much less than at DM88 or DM89. Two factors can explain the low recovery in the soil at PYb89: leaching of the floodwater, and periodic wetting by heavy rain followed by long dry periods. Loss of added N by fixation on 2:1 clay minerals were observed in some studies (Schnier *et al.*, 1987), but it is not a factor in the Northeast because of the low clay content and predominance of kaolinitic clay.

Management such as better timing of single or split chemical fertilizer doses, and deep placement of large chemical fertilizer doses reduced N losses and increased the yield benefit of added chemical N fertilizer (Zhu *et al.*, 1989). Nevertheless, such measures would be inappropriate to rice culture in the Northeast because the green manure application must be incorporated prior to rice transplantation. So, although N losses were high, ploughing down 80-90 day old *S. rostrata*, added a high equivalent rate of N fertilizer. Even significant N losses from the system did not limit a significant yield benefit to the rice.

3.5 Conclusion

The results of the **^{15}N** and **Yield Experiments** lead to the conclusions that on fine loamy to coarse loamy isohyperthermic soils in Northeast Thailand, the incorporation of *S. rostrata*:

1. released N through decomposition and mineralization, which increased rice yield potential from 14-27%, when using P and K fertilized green manure in sandy nonsaline soil;

2. increased the mass of straw and grain, such that the N yield of the rice crop increased significantly over the control;

3. resulted in significant losses of added N, as high as 80% on sandy soil, which supports the practise of supplying more green manure than is necessary, but suggests that some means be found for reducing losses; and,

4. supplied sufficient N to achieve a high proportional uptake (~30%) of added N, despite the 50-60% which was surplus to crop requirements.

3.6 References

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TABLE 3.1 Mass of S. rostrata incorporated before rice transplantation into the larger plots.

	DM88	DM89	PYa88	PYb89
FERTILIZED				
Age (days)	86	84	86	63
Mg ha^{-1} (70% H_2O)	22.2	20.2	8.1	9.0
(St. dev.)	(5.9)	(6.2)	(10.2)	(4.6)
%N (dry)*	2.5	2.5	2.5	2.5
N (kg ha^{-1})	146.4	152.0	53.5	67.3
(St. dev.)	(39.0)	(46.7)	(62.0)	(34.3)
UNFERTILIZED				
Age (days)	86	84	86	63
Mg ha^{-1} (70% H_2O)	6.0	15.4	17.8	4.4
(St. dev.)	(3.4)	(2.3)	(10.0)	(1.1)
%N (dry)*	2.5	2.5	2.5	2.5
N (kg ha^{-1})	39.8	116.0	117.0	33.2
(St. dev.)	(22.6)	(17.5)	(59.8)	(8.5)

* st. dev. = 0.3

TABLE 3.2 Total yields, N content and mass of N, of both grain and straw at DM88, R-DM89, and DM89. "R" denotes the residual experiment: no green manure was added in 1989, in order to determine if the 1988 treatments would have carry-over effects.

SITE/ TREATMENT	Grain (d.w.) Yield (Mg ha^{-1})	%N	N (kg ha^{-1})	Straw (d.w.) Yield (Mg ha^{-1})	%N	N (kg ha^{-1})
DM88						
FGM	2.99^{c}	0.80^{b}	26.8^{c}	9.07^{b}	0.53^{a}	50.0^{b}
GM	1.97^{b}	0.94^{a}	20.0^{b}	4.38^{a}	0.53^{a}	23.4^{a}
CTL	1.46^{a}	0.90^{ab}	14.6^{a}	3.07^{a}	0.49^{a}	14.7^{a}
(SEM)	(0.12)	(0.04)	(1.4)	(0.41)	(0.03)	(1.0)
R-DM89						
RFGM	2.14^{a}	1.29^{ab}	16.9^{a}	2.06^{a}	0.81^{a}	18.4^{a}
RGM	2.11^{a}	1.34^{a}	17.8^{a}	2.02^{a}	0.76^{a}	17.1^{a}
RCTL	2.30^{a}	1.19^{b}	16.3^{a}	2.20^{a}	0.85^{a}	20.7^{a}
(SEM)	(0.09)	(0.05)	(1.3)	(0.18)	(0.04)	(1.3)
DM89						
FGM	2.64^{a}	1.05^{a}	31.4^{b}	8.22^{b}	0.48^{a}	46.1^{b}
GM	2.47^{a}	0.97^{a}	26.1^{a}	5.28^{ab}	0.49^{a}	32.4^{ab}
CTL	2.13^{a}	0.97^{a}	22.8^{a}	3.27^{a}	0.51^{a}	22.5^{a}
(SEM)	(0.25)	(0.04)	(1.5)	(0.94)	(0.02)	(4.7)

Different letters in the column indicate significantly different means at Alpha ≤ 0.05

TABLE 3.3 Total yields, N content and mass of N, of both grain and straw at PYa88, and R-PYa89. "R" denotes the residual experiment: no green manure was added in 1989 in order to determine if the 1988 treatments would have carry-over effects.

SITE/ TREATMENT	Grain (d.w.) Yield (Mg ha^{-1})	Grain (d.w.) %N	Grain (d.w.) N (kg ha^{-1})	Straw (d.w.) Yield (Mg ha^{-1})	Straw (d.w.) %N	Straw (d.w.) N (kg ha^{-1})
PYa88						
FGM	0.21^{a}	1.31^{a}	2.47^{a}	1.31^{a}	1.05^{ab}	13.2^{a}
GM	0.31^{a}	1.33^{a}	4.13^{a}	2.12^{b}	1.12^{a}	24.6^{b}
CTL	0.25^{a}	1.17^{a}	2.98^{a}	1.28^{a}	0.83^{b}	10.0^{a}
(SEM)	(0.07)	(0.06)	(0.90)	(0.25)	(0.08)	(2.9)
R-PYa89						
RFGM	0.07^{a}	1.07^{a}	0.75^{a}	2.04^{a}	1.09^{a}	19.3^{a}
RGM	0.21^{a}	1.17^{a}	2.46^{a}	2.89^{a}	0.79^{a}	24.3^{a}
RCTL	0.25^{a}	1.07^{a}	2.68^{a}	1.46^{a}	0.72^{a}	16.3^{a}
(SEM)	(0.51)	(0.11)	(5.02)	(0.15)	(0.05)	(1.4)

Different letters in the column indicate significantly different means at Alpha ≤ 0.05.

TABLE 3.4 Total yields, N content and mass of N, of both grain and straw at PYb89.

SITE/ TREATMENT	Grain (d.w.) Yield (Mg ha^{-1})	%N	N (kg ha^{-1})	Straw (d.w.) Yield (Mg ha^{-1})	%N	N (kg ha^{-1})
PYb89						
FGM	1.90^{a}	0.91^{a}	18.83^{a}	2.40^{a}	0.45^{a}	12.39^{a}
GM	1.73^{a}	0.91^{a}	17.23^{a}	2.12^{a}	0.46^{a}	11.20^{a}
CTL	1.54^{a}	0.91^{a}	15.51^{a}	1.86^{a}	0.47^{a}	9.90^{a}
(SEM)	(0.13)	(0.03)	(1.34)	(0.20)	(0.02)	(1.07)

Different letters in the column indicate significantly different means at Alpha ≤ 0.05

TABLE 3.5 Weight of 100 filled spikelets, Percentage of filled spikelets, and the number of tillers *per* hill for all sites.

Treatment Site	100 Grain (g)	% Filled Spikelets	Tiller/ Hill
DM88			
FGM	3.14^{b}	89.8^{a}	9.8^{b}
GM	2.98^{ab}	92.0^{a}	6.5^{a}
CTL	2.82^{a}	91.2^{a}	6.3^{a}
SEM	(0.08)	(1.4)	(0.4)
R-DM89			
FGM	3.03^{a}	79.7^{a}	9.4^{a}
GM	2.54^{a}	90.0^{b}	9.3^{a}
CTL	2.53^{a}	75.5^{a}	9.5^{a}
SEM	(0.16)	(2.6)	(0.4)
DM89			
FGM	5.23^{a}	83.7^{a}	
GM	4.69^{a}	84.3^{a}	
CTL	4.22^{a}	86.6^{a}	
SEM	(0.62)	(2.4)	
PYa88			
FGM	2.07^{a}	50.9^{a}	5.3^{a}
GM	2.22^{a}	62.2^{a}	5.1^{a}
CTL	2.17^{a}	69.2^{a}	5.5^{a}
SEM	(0.09)	(5.2)	(0.4)
R-PYa89			
FGM	2.31^{a}	20.4^{a}	8.1^{a}
GM	2.30^{a}	25.6^{a}	8.2^{a}
CTL	1.89^{a}	17.8^{a}	6.4^{a}
SEM	(0.15)	(5.6)	(0.5)
PYb89			
FGM	2.81^{a}	86.6^{a}	
GM	2.77^{a}	89.4^{a}	
CTL	2.84^{a}	90.5^{a}	
SEM	(0.05)	(1.9)	

Different letters in the column of a specified site and year indicate significantly different means at Alpha ≤ 0.05.

SEM = Standard error of the mean

TABLE 3.6 - Mass of ^{15}N labelled *S. rostrata* incorporated before rice transplantation. ^{15}N labelled *S. rostrata* was incorporated into buckets situated in larger Yield Experiment plots.

	DM88	DM89	PYb89
Age (days)	60	80	80
Mg ha^{-1}(70 %H_2O)	11.7	32.6	32.6
%N (dry)	2.900	2.575	2.575
N (kg ha^{-1})	101.8	268.5	242.8
(St. dev)	(19.8)	(63.8)	(28.8)
^{15}N %Ex.	3.534	2.780	2.780

TABLE 3.7 - ^{15}N in harvested rice planted in soil in buckets. Results for the nonsaline site in 1988 and 1989 are reported as well as the saline site in 1989. The final column indicates the percentage of N in the component that is derived from green manuare.

	Plant Part	Mg ha^{-1} (St. Dev.)	%N (St. Dev.)	%Ex. ^{15}N (St. Dev.)	%NdfGM (St. Dev.)
DM88					
	Grain*	3.4	1.314	1.114	33.1
		(0.4)	(0.100)	(0.216)	(7.5)
	Straw*	9.1	0.511	1.245	35.1
		(2.5)	(0.095)	(0.235)	(6.5)
	Total	12.4			
DM89					
	Grain	2.1	1.178	0.966	34.8
		(1.0)	(0.147)	(0.375)	(13.5)
	Straw	2.9	0.772	1.008	36.3
		(1.0)	(0.366)	(0.291)	(10.5)
	Total	5.0			
PYb89					
	Grain	2.8	0.937	1.011	36.4
		(0.8)	(0.038)	(0.237)	(8.5)
	Straw	3.5	0.283	1.027	37.0
		(0.7)	(0.059)	(0.250)	(9.0)
	Total	6.3			

	Soil	kg/bucket	%N (St. Dev.)	%Ex. ^{15}N (St. Dev.)	%NdfGM (St. Dev.)
DM88		25	0.047	0.070	2.0
			(0.009)	(0.031)	(0.9)
DM89		25	0.042	0.236	8.5
			(0.004)	(0.064)	(2.3)
PYb89		25	0.018	0.107	3.8
			(0.008)	(0.078)	(4.4)

%NdfGM = % N derived from Green Manure

St. dev. = standard deviation

* values taken from plot yields DM88 because no bucket yields were recorded for DM88.

TABLE 3.8 Disposition of N from *S. rostrata* ^{15}N in buckets. Six buckets were sunk into the plots of the Yield Experiment. The DMa88 and DMb89 sites were separated from each other by about 200m. The soils were both coarse loam (50% sand and 10% clay). The PYb89 soil was a nonsaline fine loam (73% sand and 5% clay).

	Component	N kg ha^{-1} (St. Dev.)	%Ex. ^{15}N (St. Dev.)	%RNfGM (St. Dev.)
DM88				
	Grain	35.9	1.114	6.3*
		-	(0.216)	(1.43)
	Straw	44.4	1.245	6.7**
		-	(0.235)	(1.2)
	Soil	1810.6	0.074	35.1
		(251.6)	(0.031)	(17.2)
	Total			48.2
DM89				
	Grain	24.7	0.966	5.7
		(11.3)	(0.375)	(1.1)
	Straw	19.9	1.008	5.3
		(4.7)	(0.291)	(1.0)
	Soil	1415.4	0.236	40.0
		(0.0)	(0.064)	(4.3)
	Total			51.0
PY89				
	Grain	25.6	1.011	7.8
		(6.9)	(0.237)	(3.6)
	Straw	10.1	1.027	3.0
		(3.1)	(0.250)	(0.9)
	Soil	648.7	0.107	11.0
		(266.4)	(0.078)	(7.1)
	Total			21.8

%RNfGM = % Recovery of N from Green Manure

* and ** These calculations are based on the yield from the plots not from the buckets. This is because no component yields from the pots were recorded. Therefore,

* = ((grain yield 2.99 Mg ha^{-1} * 1.2% N)/(6.6 Mg ha $^{-1}$ added S. rostrata *2.84% N)) * %NdfGM(~33%)

** = ((straw yield 9.07 Mg ha^{-1} * 0.53% N)/(6.6 Mg ha^{-1} added S. rostrata *2.84% N)) * %NdfGM(~35%)

TABLE 3.9 Comparing N yield from grain and straw yield from the CTL and FGM field plots at DM88, DM89, and PYb89.

	Plant Part	Yield Mg ha^{-1} Control (SEM)	Yield Mg ha^{-1} FGM (SEM)	%N Control (SEM)	%N FGM (SEM)	N kg ha^{-1} Control (SEM)	N kg ha^{-1} FGM (SEM)
DM89							
	Grain (dry)	1.5^{a}	3.0^{b}	1.20^{a}	1.20^{a}	14.6^{a}	26.8^{b}
		(0.1)	(0.1)	(0.04)	(0.04)	(1.5)	(1.4)
	Straw (dry)	3.1^{a}	9.1^{b}	0.49^{a}	0.53^{a}	15.0^{a}	48.1^{b}
		(0.4)	(0.4)	(0.03)	(0.03)	(1.0)	(1.0)
Means within rows followed by different letters indicate significance at P<0.05.							
DM89							
	Grain (dry)	2.1^{a}	2.6^{a}	0.97^{a}	1.05^{a}	22.8^{a}	31.4^{b}
		(0.3)	(0.3)	(0.04)	(0.04)	(1.5)	(1.5)
	Straw (dry)	3.3^{a}	8.2^{b}	0.51^{a}	0.48^{a}	22.5^{a}	46.1^{b}
		(0.9)	(0.9)	(0.02)	(0.02)	(4.7)	(4.7)
Means within rows followed by different letters indicate significance at P<0.05							
PYb89							
	Grain (dry)	1.5	1.9	0.91	0.91	15.5	18.8
		(0.1)	(0.1)	(0.03)	(0.03)	(1.3)	(1.3)
	Straw (dry)	1.9	2.4	0.47	0.45	9.9	12.4
		(0.2)	(0.2)	(0.02)	(0.02)	(1.1)	(1.1)

None of the PYb89 means within rows were significantly different at ≤ 0.05.

FGM = Fertilized Green Manure Treatment

dry = dry mass

$$SEM = \frac{\text{sqrt (mean square for error on the anova or covariate analysis)}}{\text{sqrt (6)}}$$

TABLE 3.10 Comparison of Difference and Isotopic Methods to calculate N use efficiency.

	Plant Part	N Use Eff. Diff. *	Isotope (St. Dev.)
DM88			
	Grain	9.8	6.3 (1.4)
	Straw	17.6	6.7 (1.2)
	Total	27.4	13.0
DM89			
	Grain	4.7	5.7 (1.1)
	Straw	15.0	5.3 (1.0)
	Total	19.7	11.1
PYb89			
	Grain	8.9	7.8 (3.6)
	Straw	5.5	3.0 (0.9)
	Total	14.4	10.8

Isotope Efficiency is based upon %RNfGM (Table 3.8)

Difference Method uses Control & FGM treatment

* No standard deviations are reported because the calculation uses the average yields and the average N content.

APPENDIX 3.1 Conditions which resulted in failure to produce a green manure crop. Several attempts to grow *S. rostrata* under various conditions failed, not only due to excessive salinity, but salinity in combination with insufficient precipitation.

Site	Salinity dS m^{-1} (St. dev.)	Concurrent conditions	Observed effect on *S. rostrata*
PY1	~20.0 (2.0)	Flooded	High mortality after emergence. Resistant plants were stunted.
PY2	~ 5.3 (0.7)	Drought	Poor emergence and growth.
PY3	Visible salt patches		Emergence near zero.
PY4	~11.0 (composite sample)	Drought	Zero emergence.
PY5	~0.5	Water Buffalo	Emergence uninhibited, but crop destroyed due to grazing.

Sites PY1 through PY5 were all at Pra Yeun. The information is presented for the benefit of those, who might try to grow *S. rostrata* on saline soils.

CHAPTER 4 SYNTHESIS

The initial stimulus for using *S. rostrata* as a green manure in Northeast Thailand was its speedy accumulation of fixed nitrogen even under flood and/or salt stress conditions (Awonaike, 1988; Marqueses *et al.*, 1985; and Evans and Rotar, 1987). Greater grain yields were hypothesized for farmers who would adopt the practise of green manuring with *S. rostrata*. However, Ragland and Arunin (1987) observed that *S. rostrata* grown on the infertile soils of the Northeast did not attain as much biomass as reported in the Philippines or Senegal (Marqueses *et al.*, 1985; Dreyfus *et al.*, 1983), unless the crop received P and K fertilization. Despite having the lowest grain yields in Thailand (Prapertchob, 1987), Northeast farmers could not be convinced to use chemical fertilizer on a green manure crop because it cannot be eaten by people or used as animal fodder. It is a Thai governmental policy for this region to increase its staple rice crop production. Thus the question: does *S. rostrata* (fertilized with P and K) have potential to remedy low soil nitrogen fertility under conditions prevalent in Northeast Thailand?

This research explored the use of *S. rostrata* as a green manure to improve the infertile, sandy, saline soils of Northeast Thailand. The essential premise to the work was that P and K fertilization (*i.e.* 37.5 kg ha^{-1}, both of, K_2O and P_2O_5) would improve *S. rostrata* biomass. This premise was confirmed under nondrought and nonsaline conditions. *Sesbania rostrata* did not respond to P and K fertilization on arid or saline (12 dS m^{-1}) soils.

Nitrogen mineralization from *S. rostrata* incorporated into paddy soils was monitored. Ammonium-N accumulations, following incorporation of the *S. rostrata* green manure started immediately and reached a steady state within 10-31 days (Chapter 2). Significant differences in NH_4^+-N accumulation were observed among the treatments. The greater the original green manure input the higher the concentration of NH_4^+-N in the soil (FGM > GM > CTL). It was inferred that a steady state was achieved because volatilization, denitrification or leaching equalled mineralization. This was confirmed by high values for the rate constants, but low values for the ammoniacal N, and subsequently by low recovery of ^{15}N in soil and rice crops following *S. rostrata* incorporation. Immediate transplanting of rice following plough down of *S. rostrata* green manure is therefore important, not only because it fits into the Northeast rice culture, but because the release of NH_4^+-N begins immediately and so, too, can volatilization.

The amount of N from *S. rostrata* that remained in the soil or was transferred to the subsequent rice crop was also determined (Chapter 3). Added N comprised ~30% (*i.e.*

%NdfGM) of the N in the rice crops, whereas the recovery of added N (%RNfGM) was ~10-13%. Between 10 and 40% of the added N remained in the soil, and the remainder was lost to leaching, denitrification, or volatilization.

A clear N yield benefit of 14-27%, calculated by the Difference Method, was gained using the P and K fertilized green manure (FGM) on rice (Chapter 3). Rice yields on: 1) droughty soils showed no significant improvement (CTL = GM = FGM); 2) sandy, saline soils increased with nonfertilized *S. rostrata* (GM); and, 3) yields on sandy nonsaline, nondroughty soils increased 2.5 fold with pre-transplantation incorporation of P and K fertilized *S. rostrata* green manure (FGM). Rice yields did not increase with P and K fertilizer added directly to the rice after transplantation either with or without *S. rostrata* green manure.

Crop yields in the Northeast are generally poor. Thus, despite the low recovery of added N, the response by rice to green manure is dramatic and consistent. Annual addition of up to 20 Mg ha^{-1} of N rich green manure meets the crop N requirement of these infertile soils. In the context of the Northeast of Thailand, where the cost of chemical fertilizers is high compared to *per capita* income, and there is a need to increase N for the staple rice crop, green manuring with *S. rostrata* is a potential resource. The socio-economic assessment of these results is presented in Appendix 2.

4.1 References

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APPENDIX 1 Rice Culture with Sesbania rostrata Green Manuring in Northeast Thailand.

One rice crop is grown each year on the rainfed areas of the Northeast (Figure 5.1). The dry season varies in length, but usually begins in November and runs until the end of April. During the dry season little or no rain falls. Some vegetable crops, however, can be grown at the end of the rainy season on residual soil moisture, but by January or February the soil is too dry for vegetable crops unless they can somehow be irrigated.

The month of May marks the beginning of the monsoons (the rainy season during which winds blow from the southwest) and typhoons (violent tropical cyclones originating in the W. Pacific). Traditionally farmers plough their fields as soon as water ponds on the soil surface. At this point, the ground will be soft enough for a plough drawn by a water buffalo to turn over the earth (Figure 5.2), achieving a 15 cm deep furrow slice with a water buffalo (W.B.), and 20-25 cm deep furrow slice with a hand guided motorized plough (M.P.). Thus, the objective of this first ploughing is to break the earth, and reduce the weed load on the soil such that the second ploughing in July or August, prior to rice transplantation, is less arduous. Not all the fields may be ploughed immediately, because the farmer works at a leisurely pace, and if the fields are not all ploughed, it is not considered important. In the Northeast, the land is divided into many small paddies. This is done to facilitate: i) manual land levelling by hoe; and, ii) bunding or diking the paddies to maintain flooding during the rainy season.

The green manure crop, *Sesbania rostrata*, should be planted after the first heavy rains, in order for it to grow a minimum of 60 days before being ploughed down to make way for the subsequent rice crop. The *S. rostrata* seed is soaked in water in the sun for two days to soften its hard seed coat and break dormancy. It it is then broadcast onto the ploughed land (Figure 5.3).

Sesbania rostrata seed production: Growing *S. rostrata* for its own seed can also begin with the first rains. The land needs to be harrowed and then seeds are drilled into hills. The hill spacing is 50 x 100 cm.

Sesbania rostrata cannot tolerate flooding early in the life cycle, and it must, therefore, be seeded early in the rainy season when flooding is rare. The *S. rostrata* is inoculated with ORS-571 rhizobium after about 30 days growth (~June 18), when the plants reach 25-50 cm (Figure 5.4). Nodules begin to develop within a week (Figure 5.5).

Some 30 days before transplantation, the rice nurseries are planted. Rice seed is soaked for one to three days, and then set in hemp sacks in the shade, still moist, for another 2 days. During this time the sacks, only half full, are periodically given a quarter roll so that sufficient oxygen reaches all the germinating seeds. Consequently, when the rice is broadcast onto the nurseries it has already germinated and the radicle is protruding from the seed.

The rice varieties most commonly selected by Northeast farmers are the non-glutinous KDM-105, and the glutinous GK-6. These are favorite varieties because of their sweet smell and soft texture when cooked. The palatability of these tall varieties overrides the less desirable characteristic of relatively low yield potential because of susceptibility to lodging. Dwarf varieties developed for Northeast Thailand produce more than the 3.2 Mg ha^{-1} of KDM-105 and 4.2 Mg ha^{-1} of GK-6. Of the two tall varieties, the glutinous variety is more popular because of the ease of meal preparation. No cutlery is required since the rice can be squeezed into balls. Nutritionally there is little difference between the two types, and both are polished for human consumption. Consequently, even though KDM-105 is more salt tolerant than GK-6, the cultural demand for glutinous rice is greater and so it is preferentially grown even by farmers with saline land.

Special care is taken in preparation of nurseries. To grow a sufficient number of seedlings for transplantation into 1 ha, 0.2 ha of nursery are required. Nursery size (~400 m^2) is selected according to the distance over which the farmer can evenly broadcast seed when standing at the edges of the field. The paddies are flooded and are the: 1) re-ploughed with W.B. or M.P. (Figure 5.6), 2) harrowed with water buffalo or motorized plough to break up the clumps of soil so that a level surface is achieved (Figure 5.7); and finally, 3) levelled and smoothed by a hand-drawn plank (as one would smooth a poured-concrete floor) (Figure 5.8). A ditch is dug around the edges of the nursery to drain away excess water - otherwise the broadcast seed floats on the water and does not take root. Lastly, the germinated rice seed is broadcast onto the smooth levelled paddy surface from the paddy dykes (Figure 5.9) at a rate of ~260 kg ha^{-1}.

Erratic rainfall in the Northeast of Thailand is a major cause of drought during the rainy season. Therefore, the nursery is irrigated if there is a nearby dugout (Figure 5.10). Farmers without access to a dugout may lose their nurseries if drought is prolonged. In such cases, the nurseries must be reseeded. Another option, used at Pra Yeun in the dry years, was to broadcast the rice seed into the ploughed and harrowed fields directly instead of first establishing rice in a nursery. In this case, the lack of water makes green manuring unmanageable because it does not die when it is ploughed down; instead it resprouts and grows.

Rice is transplanted from nurseries in July and August, which coincides roughly with development of the 3rd tiller. However, transplantation waits for sufficient water because both the nurseries and the main fields must be flooded, to facilitate uprooting the rice plants, and their re-planting.

The fields are prepared fo. transplanting when sufficient rain water ponds (5-10 cm). The fields are re-ploughed, and then harrowed. In this project, green manure was ploughed down (incorporated) first (Figure 5.11). The Department of Agriculture recommends that seedlings should not be fertilized within the week before transplanting. Fertilization makes the plants less rigid so that they cannot stand the process of uprooting.

Nurseries are inundated only enough to have 2-3 cm of standing water. Workers then grasp a small number of plants (~10-20 small plants, or 5-10 big plants) in both hands and quickly tear them out of the earth with a swift single horizontal sweeping motion (Figure 5.12). Slow uprooting brings huge clods of soil with the roots, while upward pulling action (as opposed to horizontal) separates the stems from the roots. Having uprooted the plants, all soil is knocked off the roots by whacking them against the side of the foot (Figure 5.13). The clean transplants are then bundled into sheaves consisting of ~300-400 plants each and tied together (Figure 5.14). The bundled sheaves are left in standing water until they are ready to be moved to the main fields for transplantation. Then the sheaves are skewered through with a long bamboo pole and hauled to the fields (Figure 5.15).

Before transplanting, the tops of the transplants in the sheaves are cut off (Figure 5.16). This pruning stimulates water uptake and reduces the amount of leafy matter that will droop into the flood water, which would act as a disease vector. Each worker then takes a bundle of rice and lays it down the length of one arm, the roots hanging over the hand (Figure 5.17). Rice is planted in hills, which means that, depending on the size (age) of the transplants and the survival rate for that area, 3 to 5 plants are planted in a clump. To plant: all three to five plants are taken by the roots so that the forefinger is at crown level, and the thumb is on the roots (Figure 5.17). With a twist of the wrist, the plants are placed in the muck - not too deep so that the plant lacks oxygen nor too high so that it is not anchored in the soil and floats away with the first breeze. The farmers work quickly; planting several hectares per day. Rice recovers from the shock of transplantation within a week. Panicle initiation (*i.e.* the beginning of the reproductive phase), in the photosensitive varieties used in this experiment, begins around September 23. The panicle emerges and lengthens for the next 30 days (Figure 5.18).

*Sesbania rostrata* _seed collection_: In the Northeast, *S. rostrata* flowering starts around August 21. By this time, the plants have reached 2-4 m in height (Figure

5.19). It has yellow flowers with standard petals of 0.5-2.8 cm borne on loose racemes (Figure 5.20). Pollination is by Hymenoptera. Collection of the long (13-18 cm) browning cylindrical seed begins around early October (Figure 5.20). The dried pods are threshed by beating them with a stick or rubbing together by hand or foot (Figure 5.21) The seeds (~2 x 4 mm) are dried in the sun for several days, winnowed, and put into sacks for the subsequent season (Figure 5.22).

About October 23, the rice crop is beginning to flower. After flowering, vegetative growth ceases. GK-6 may reach a maximum height of ~150 cm, while KDM-105 may attain 140 cm. For the next 30 days, the spikelets fill and mature. The complete life cycle of the photosensitive varieties varies between 120-150 days, depending on how early in the season the nursery was planted (Figure 5.18).

Harvest can also be delayed a week, but it usually begins the last week of November. Hand held sickles are used to swathe the rice about one inch below the first node down from the panicle (Figure 5.24). The stems and panicles are laid down to dry in the sun (Figure 5.25). Two or three days later, sheaves can be tied, which are again skewered and hauled on a bamboo pole (Figure 5.26) to a threshing floor, where they are stacked (Figure 5.27).

The threshing floor is an area close to the field shelter (Figure 5.30) (a temporary home used during the rice growing season, while the primary dwelling is in the village maybe 1 or 2 km away). An area of ground is cleared of all weeds and dead leaf material - it is literally swept. Then manure from water buffalos is collected and mixed with water to form a thick paste, which is poured ~half an inch thick on the cleared ground until a large area is covered (~20 m^2). The paste dries and bakes in the sun to form a hard smooth surface. This area becomes the centre for threshing and winnowing the rice.

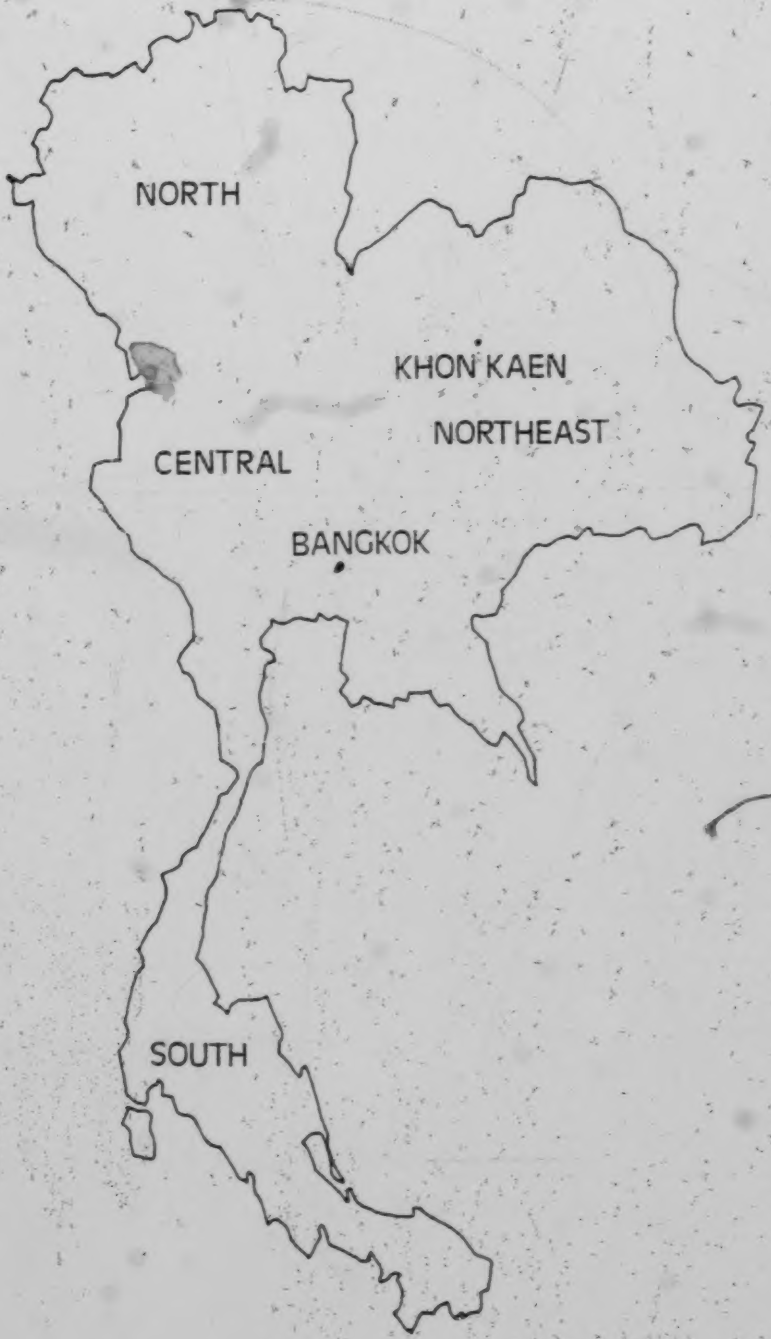
Threshing is most commonly done by hand, although some farmers hire a mechanical thresher that is driven up to their land. The mechanical thresher is not preferred, even though it makes quick work of days of manual labour, because it shreds the straw too fine and strews it out in a big pile. By contrast, the manual method of threshing leaves the straw in manageable sheaves - which are used for thatch and water buffalo fodder.

Hand threshing is accomplished by using two sticks tied together at one end. The connecting cord is ~30 cm long. The sheaf is gripped by wrapping the cord around it and locking one stick under the other. Thus, the sheaf can be raised overhead and beat down upon the threshing floor (Figure 5.28). Not more than ten strokes are needed to knock all the grain off: if the grain resists, the panicles can be rubbed together by hand.

The final product is fairly clear of chaff, but winnowing can be done by using a fan made of woven wicker

(Figure 5.29). Lastly, the unhulled rice is put into hemp sacks, and hauled to the village, where it is kept in a granary behind the home. Rice is stored unhulled.

FIGURE 5.1 REGIONS OF THAILAND



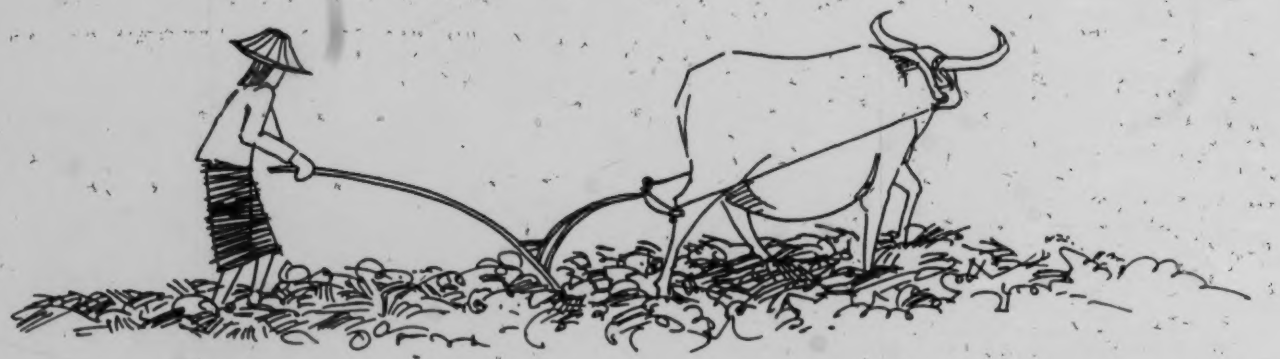


FIGURE 5.2 FIRST PLOUGHING IN MAY

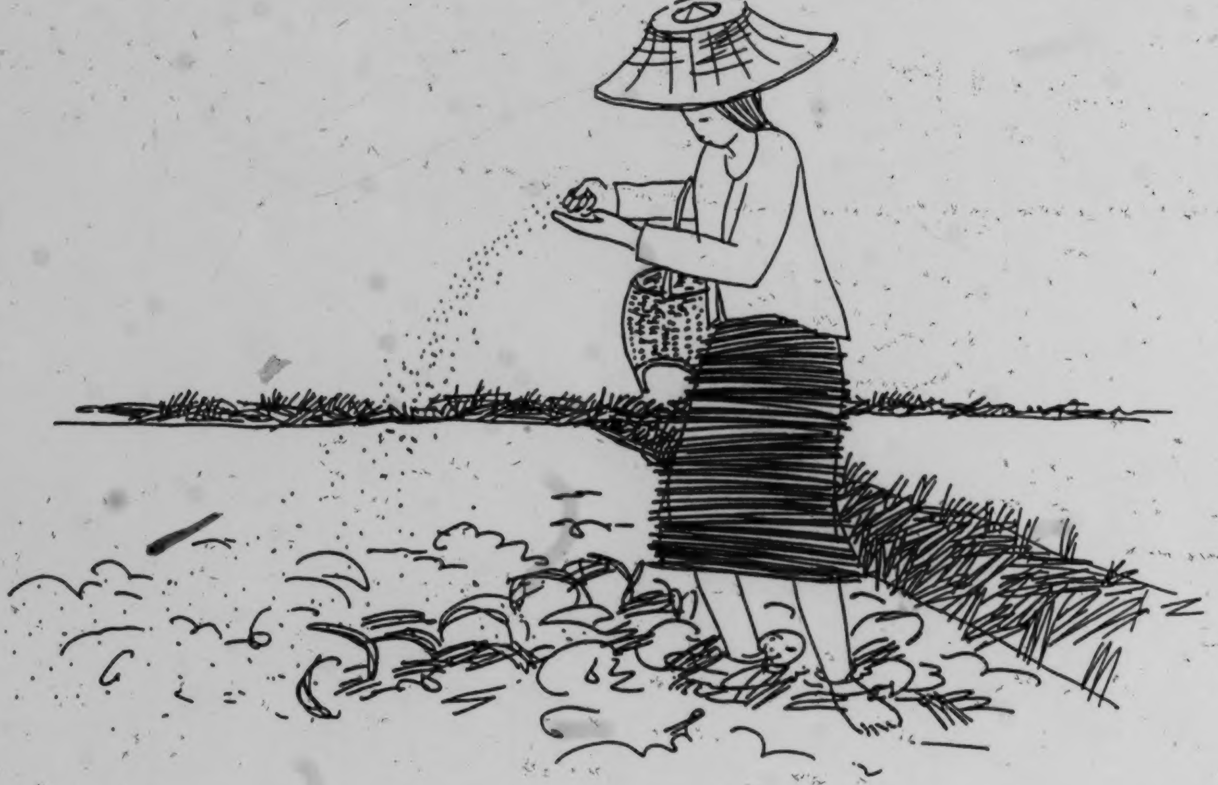


FIGURE 5.3 BROADCASTING SESBANIA ROSTRATA IN MAY

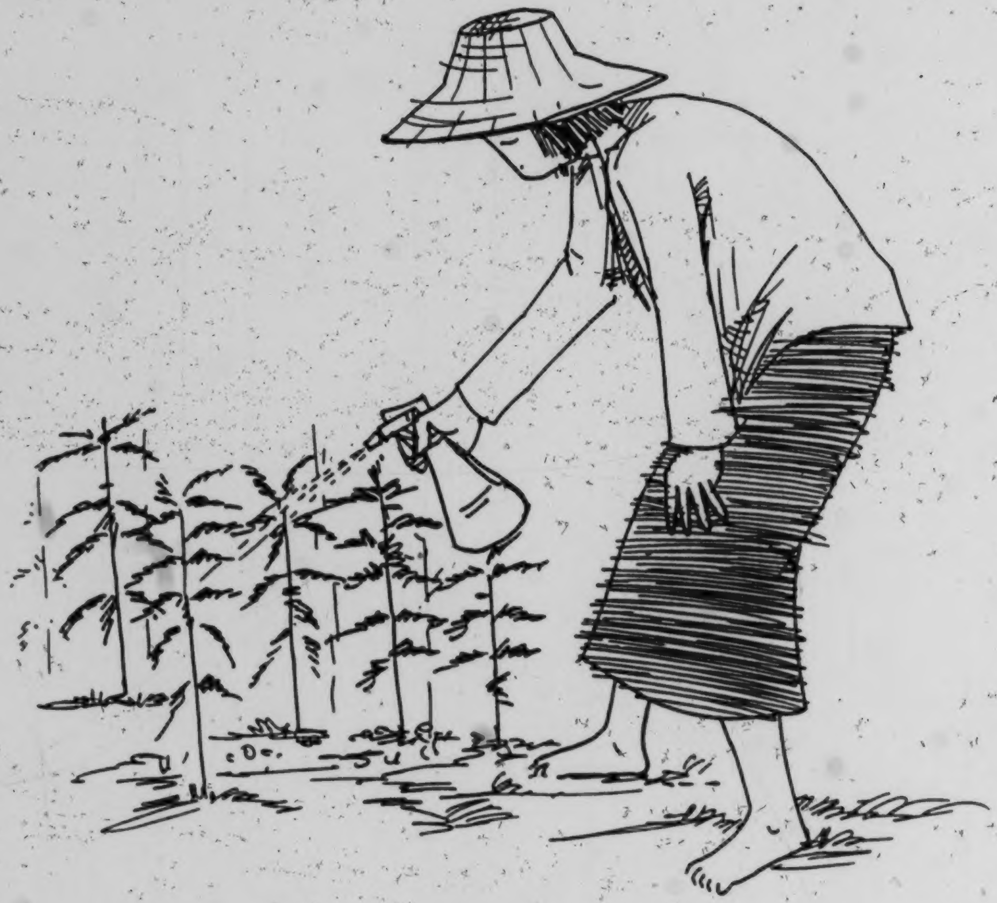


FIGURE 5.4 INOCULATING SESBANIA ROSTRATA

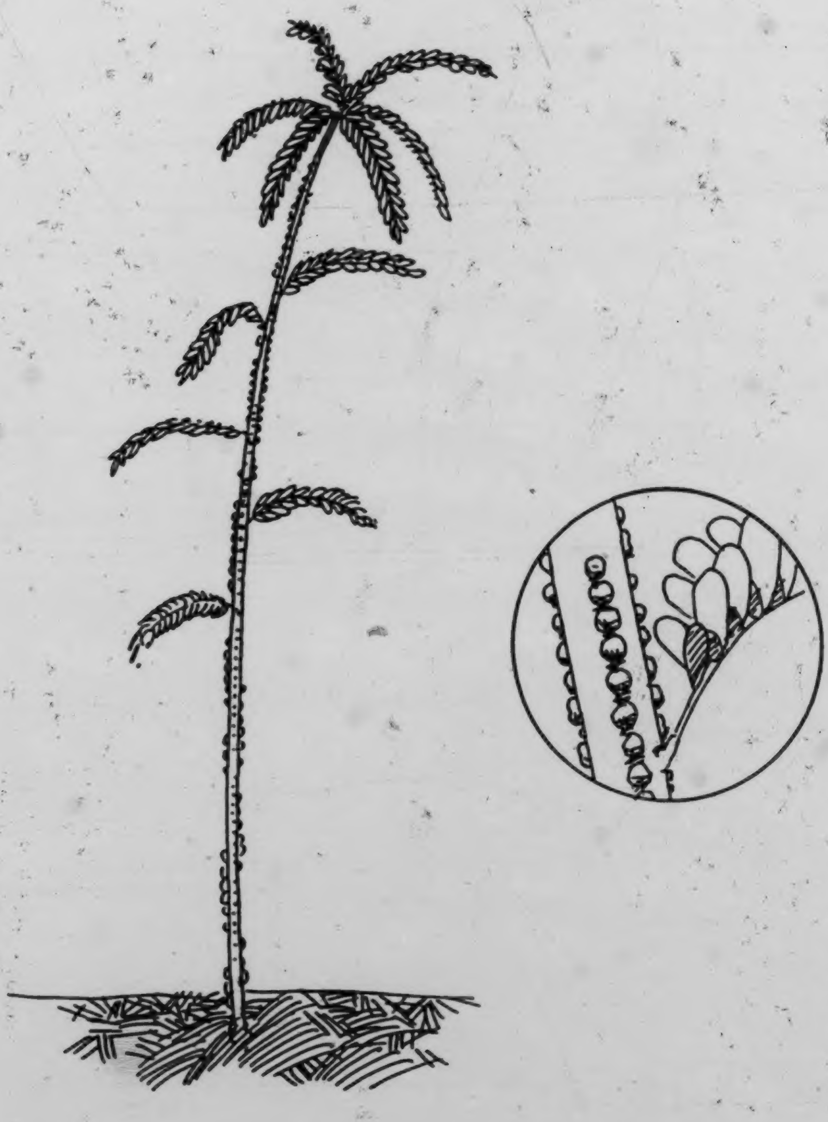


FIGURE 5.5 STEM NODULATION OF SESBANIA ROSTRATA

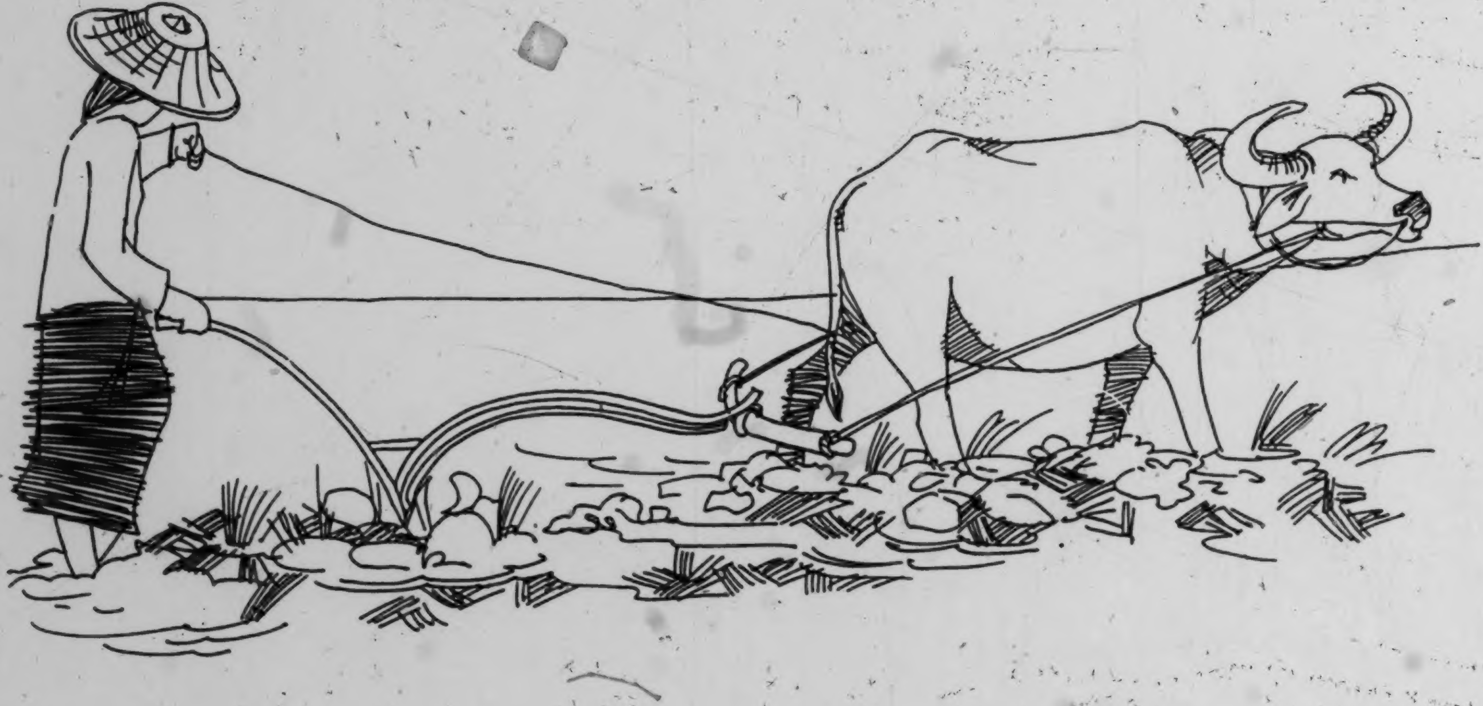


FIGURE 5.6 PLOUGHING NURSERY IN JUNE

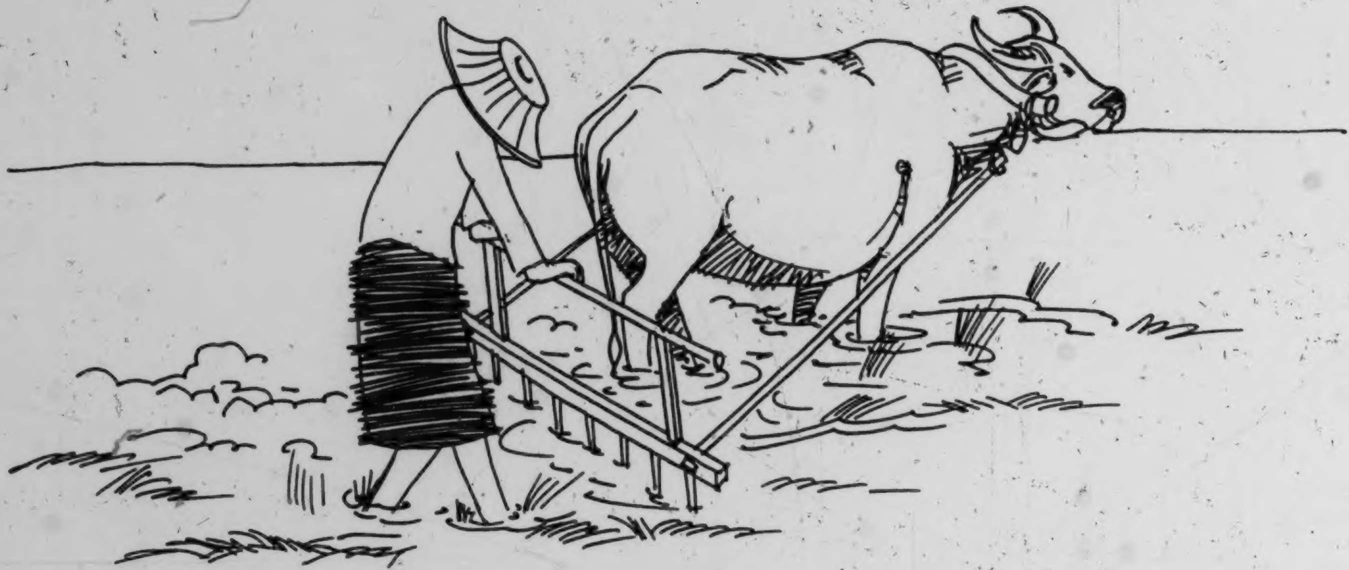


FIGURE 5.7 HARROWING THE NURSERY

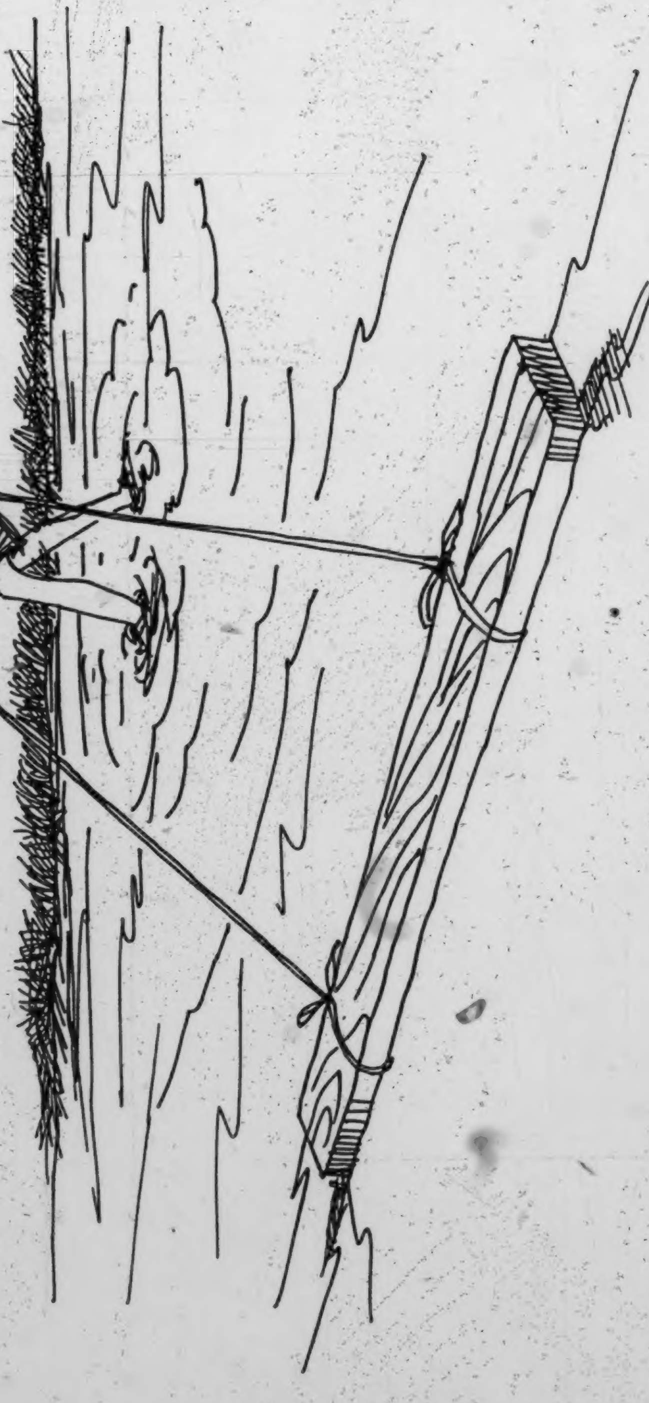


FIGURE 5.8 LEVELING THE NURSERY AND DRAINING EXCESS WATER

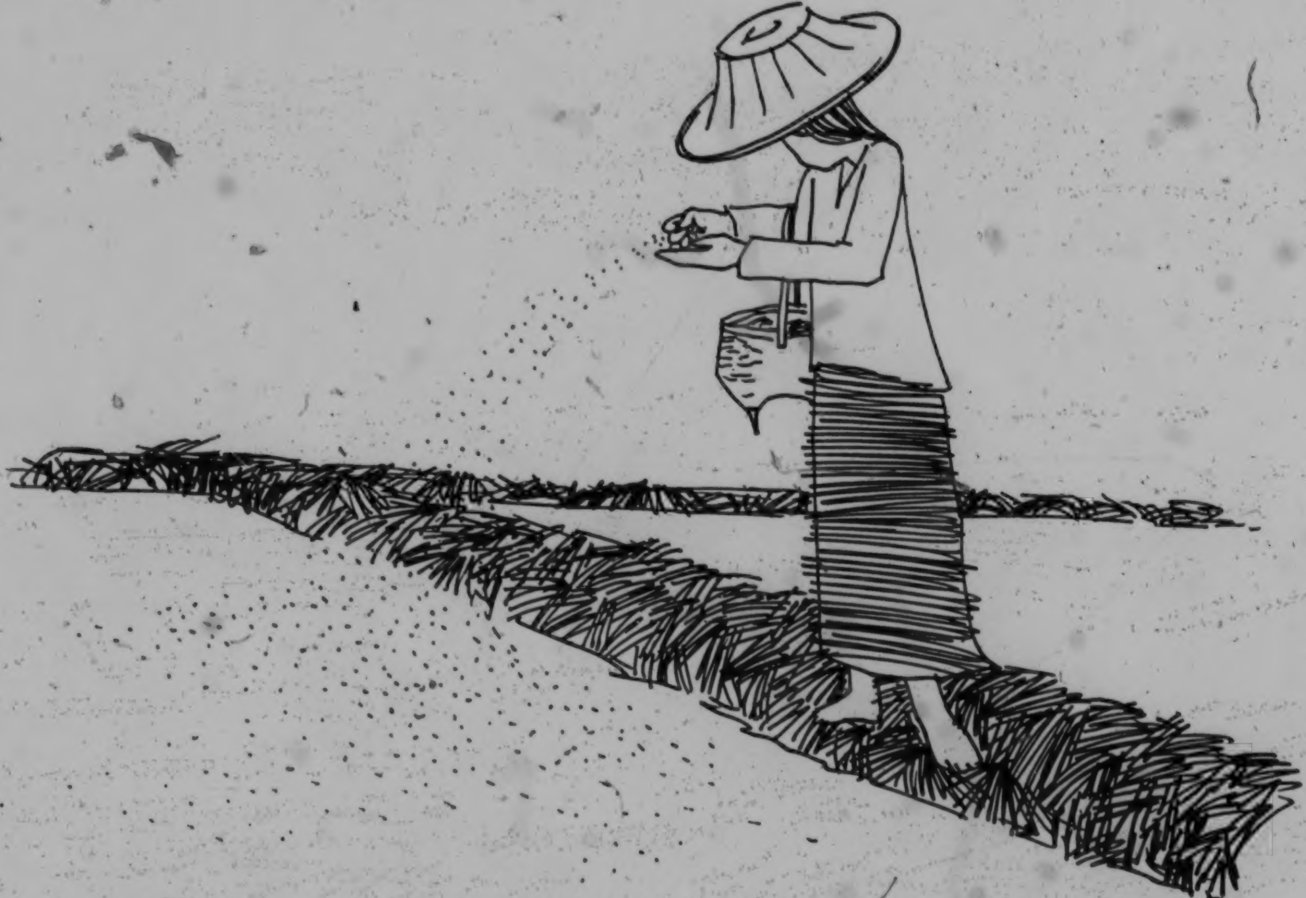


FIGURE 5.9 BROADCASTING RICE ONTO THE NURSERY FROM THE BUNDS

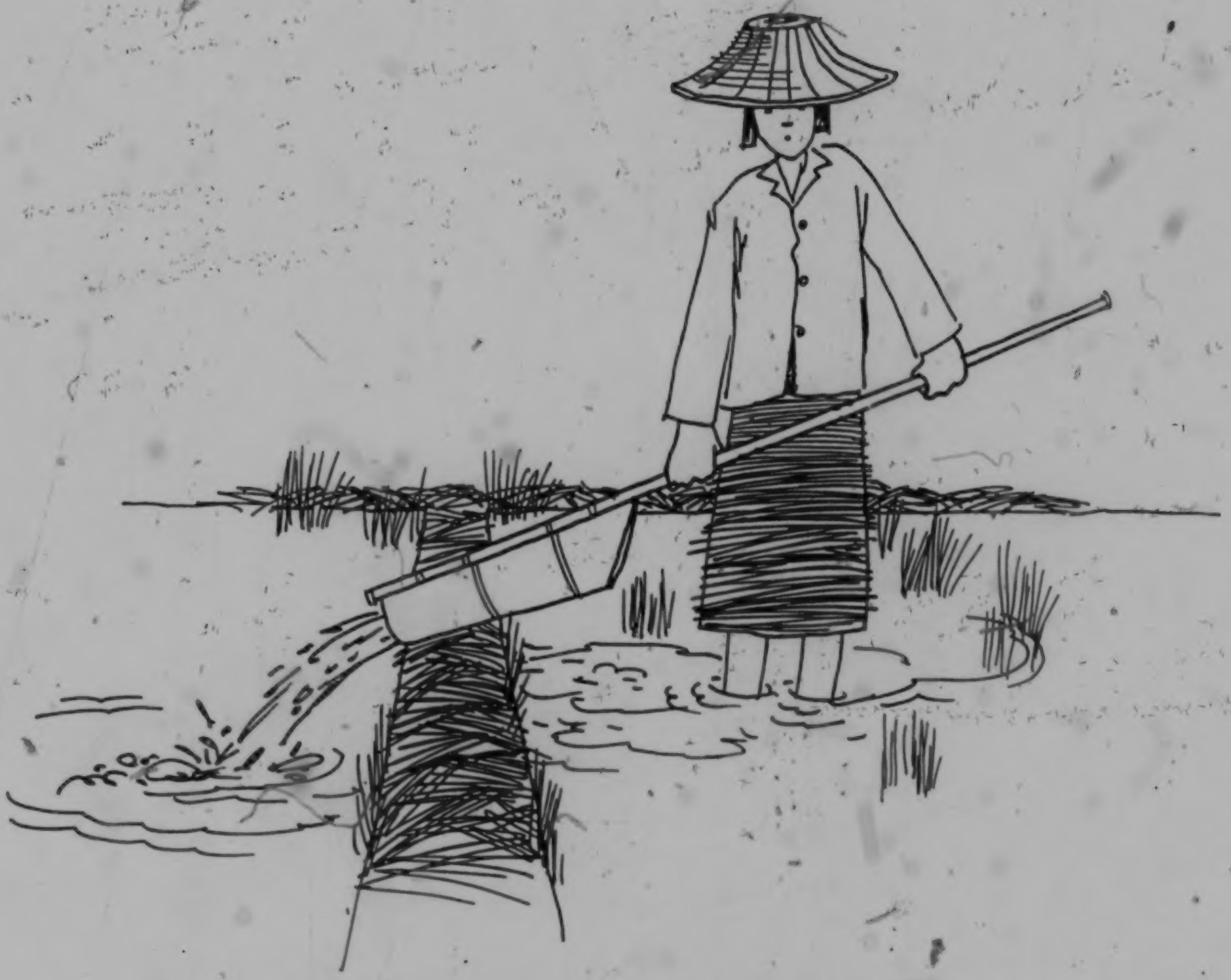


FIGURE 5.10 WATERING THE RICE NURSERIES

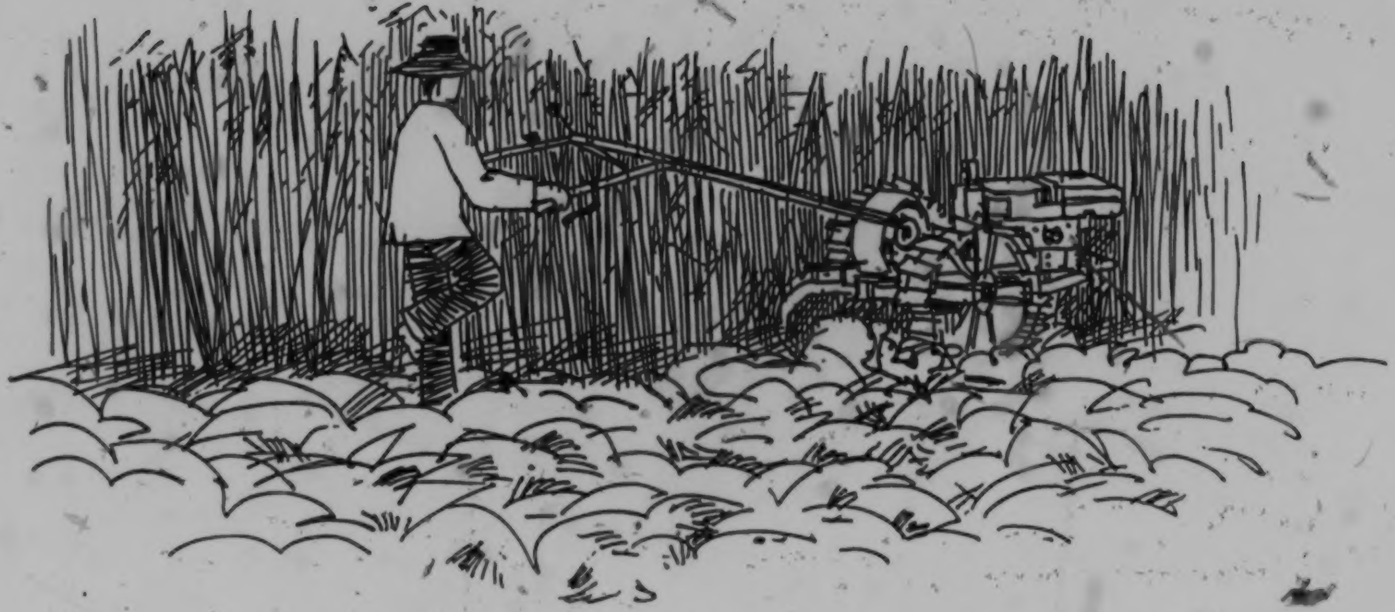


FIGURE 5.11 PLOUGHING-DOWN SESBANIA ROSTRATA PRIOR TO TRANSPLANTATION

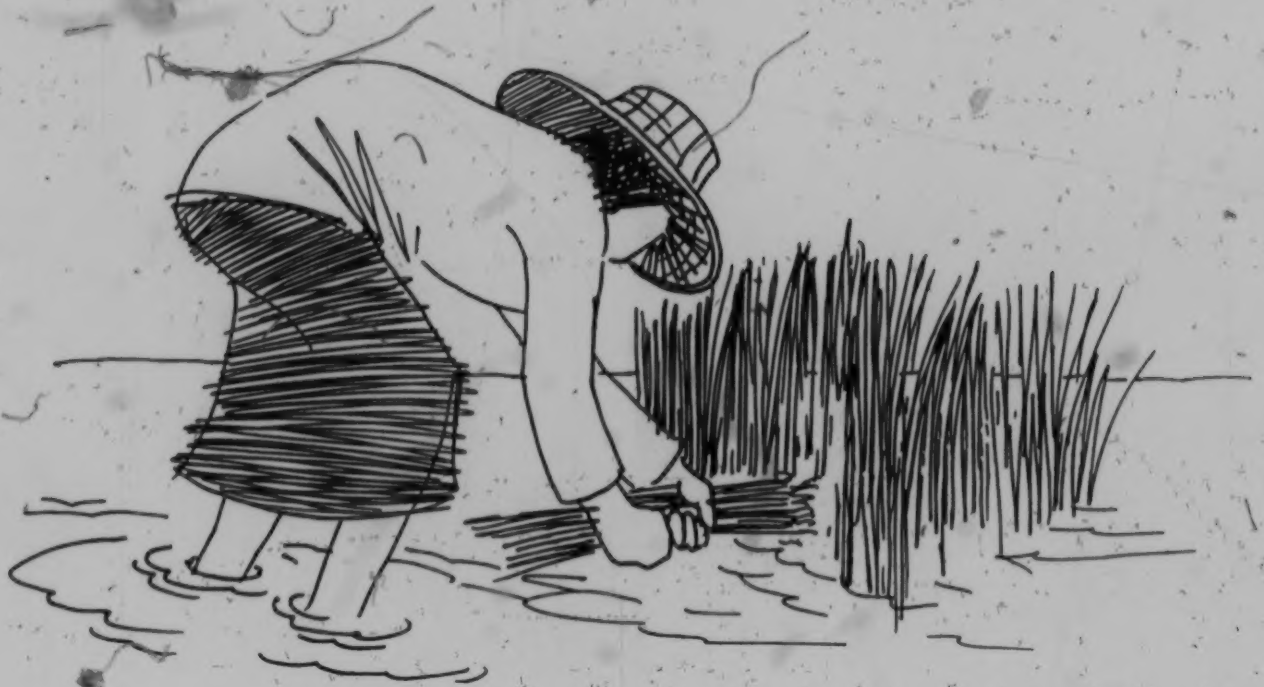


FIGURE 5.12 PULLING UP THE RICE FOR TRANSPLANTATION IN JULY OR AUGUST

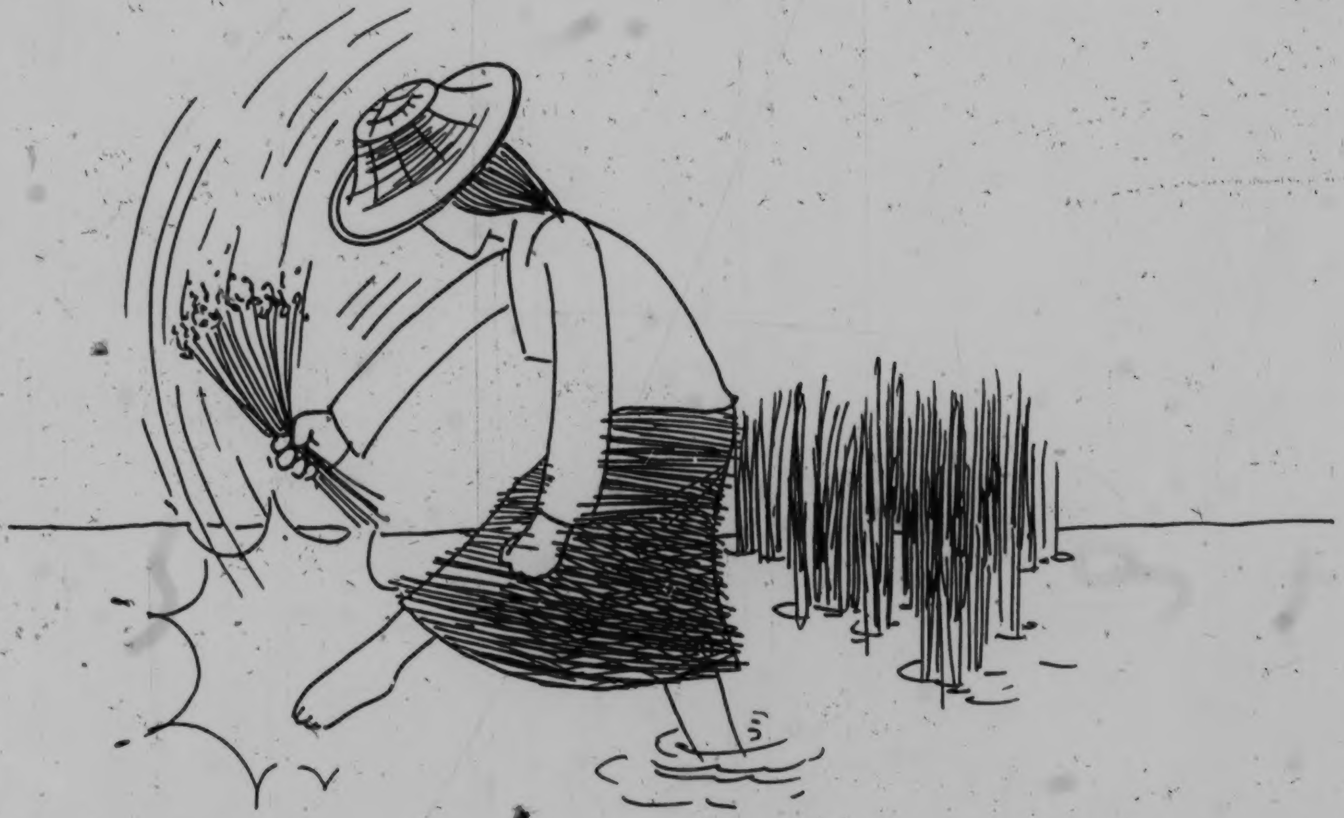


FIGURE 5.13 KNOCKING SOIL FROM TRANSPLANT ROOTS

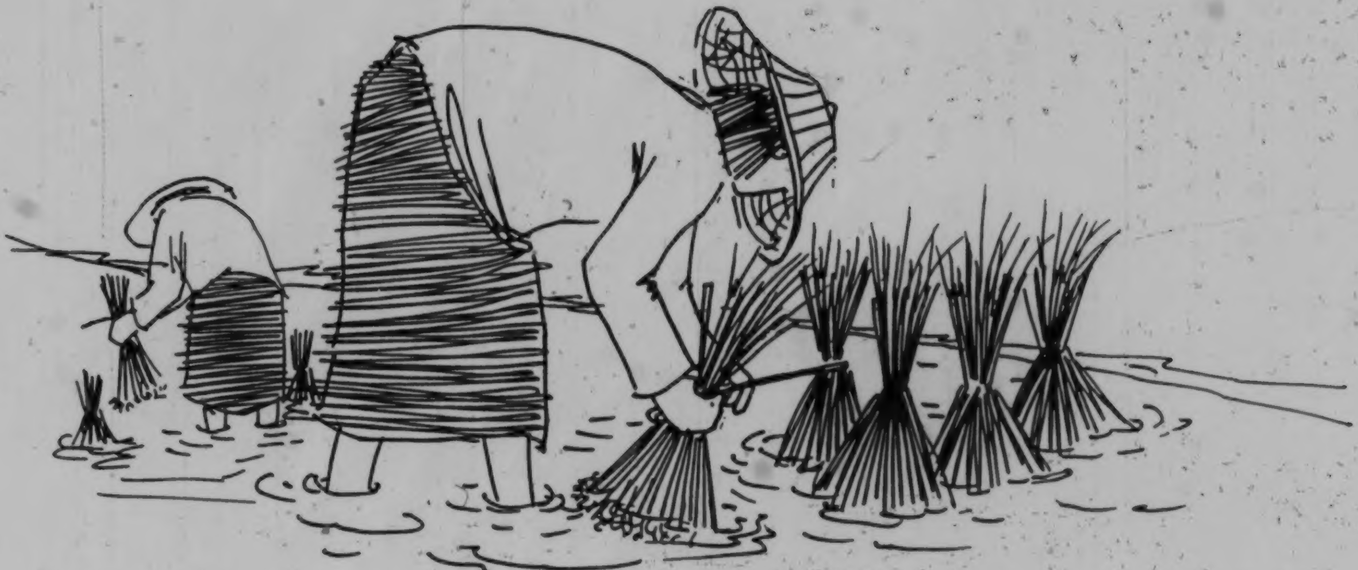


FIGURE 5.14 TYING TRANSPLANTS INTO BUNDLES FOR TRANSPORT
TO THE FIELDS

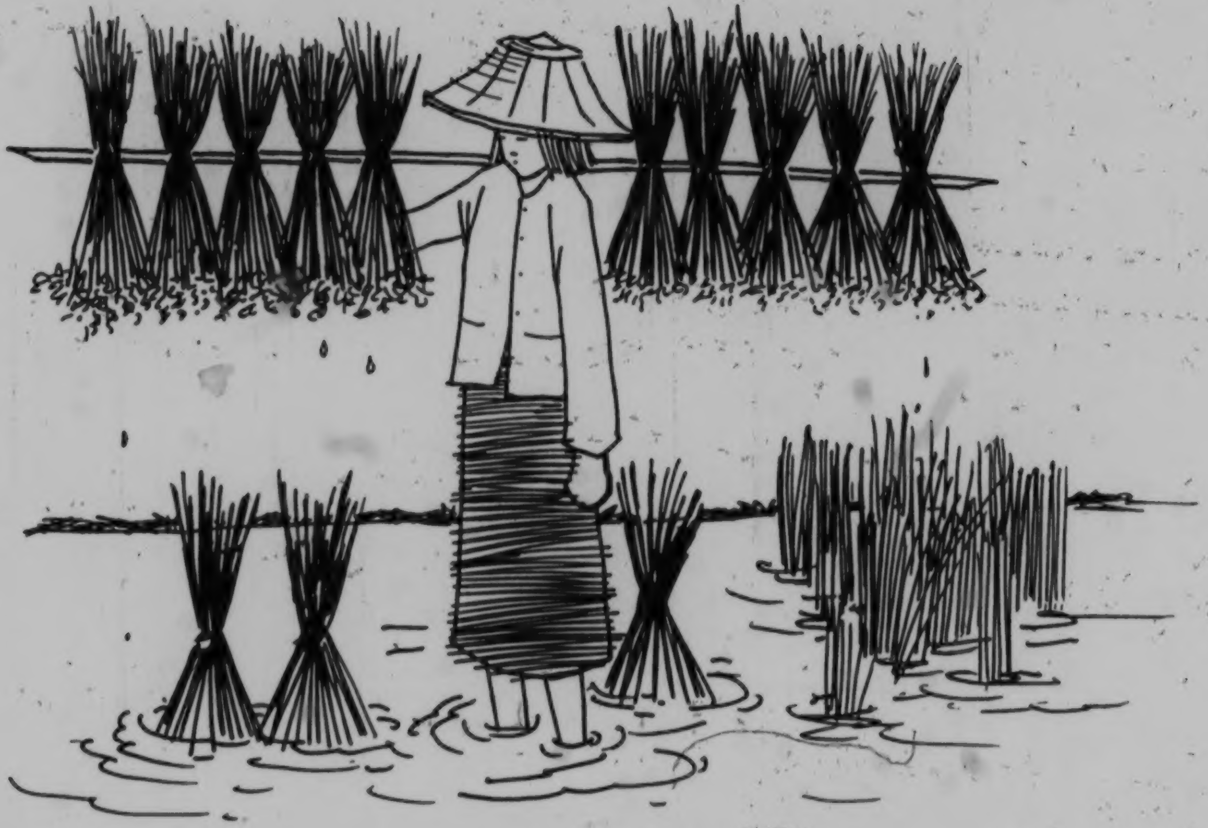


FIGURE 5.15 HAULING THE TRANSPLANTS TO THE FIELDS

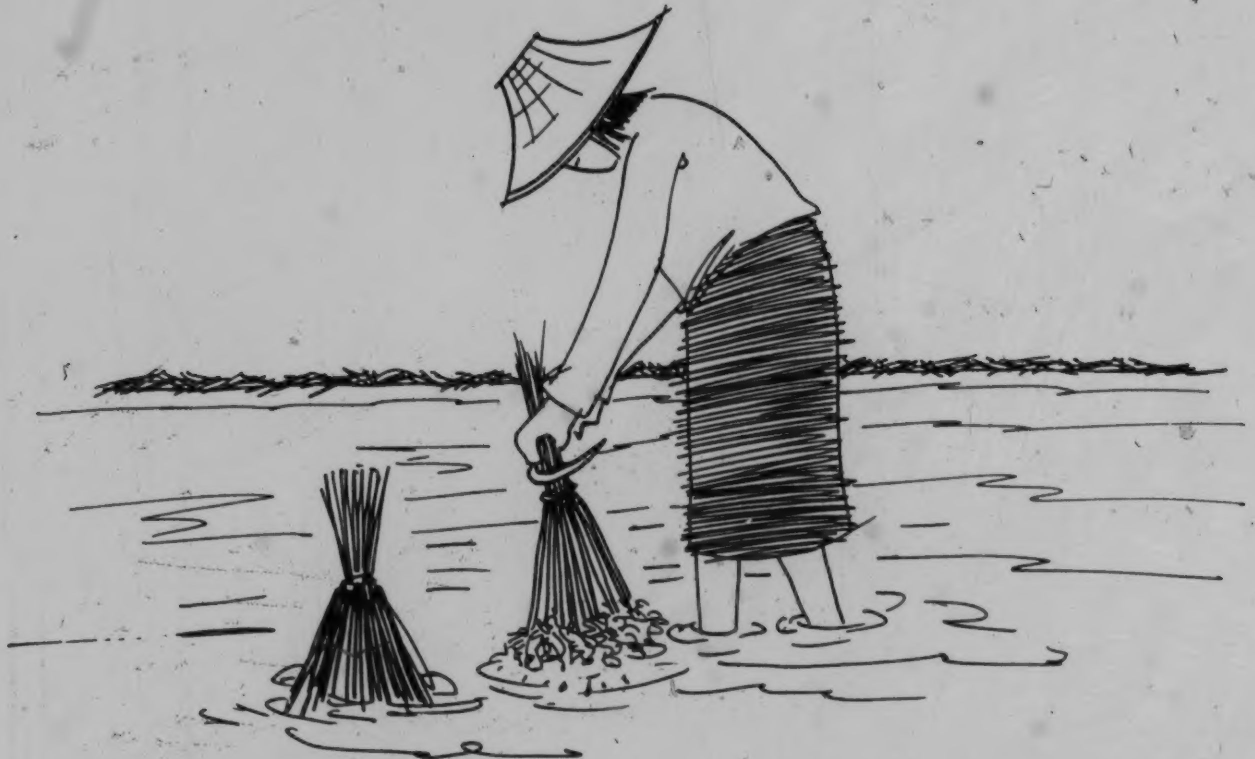


FIGURE 5.16 CUTTING OFF THE TOP OF THE TRANSPLANTS

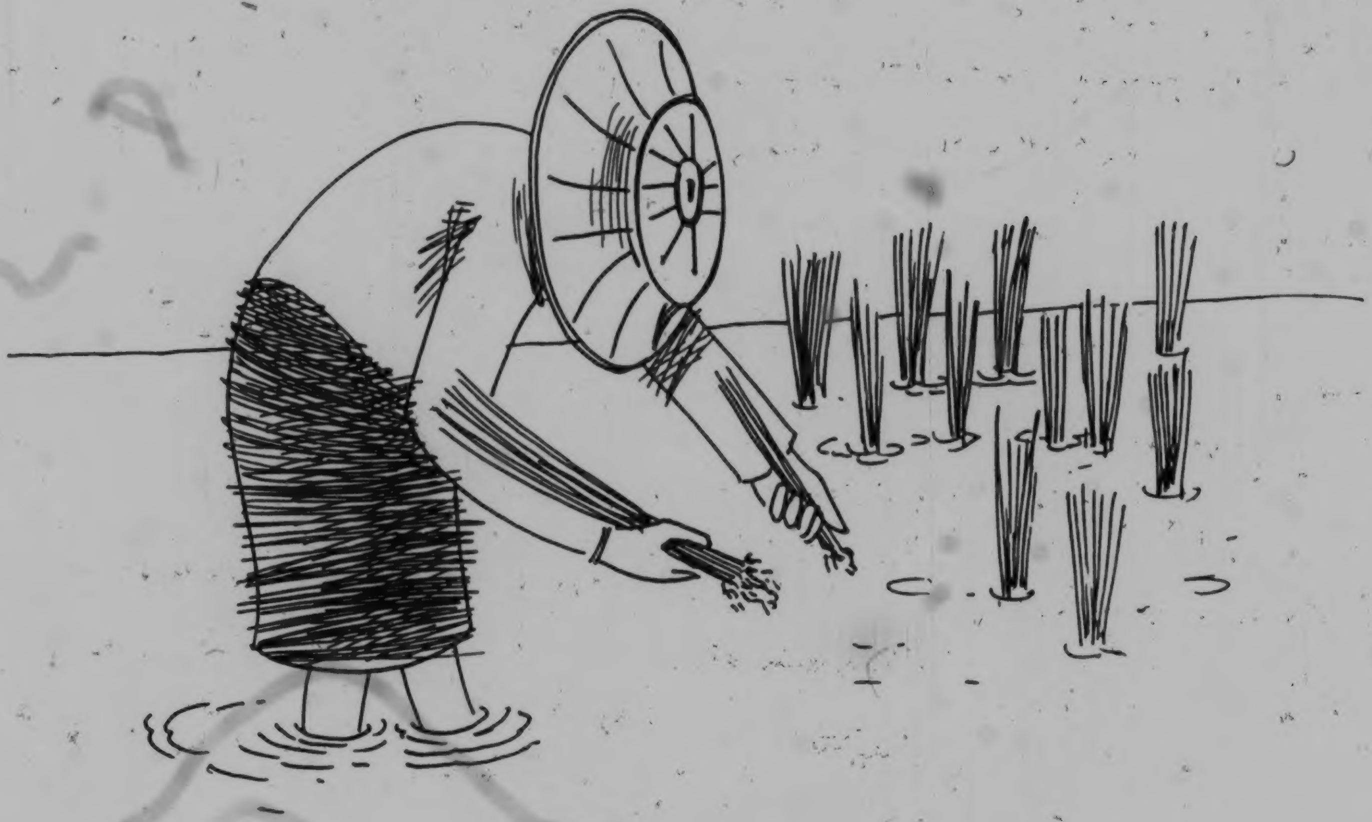
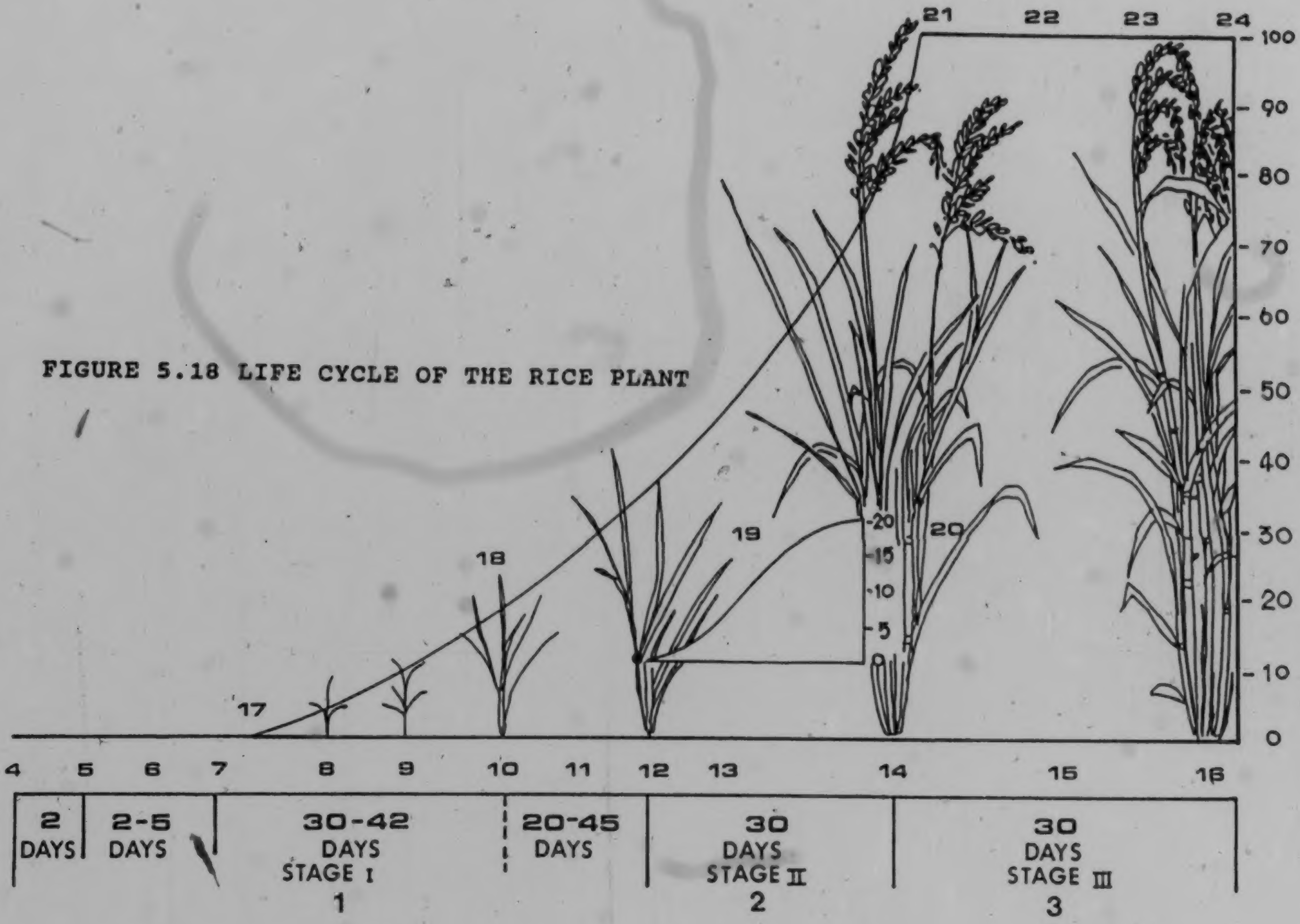


FIGURE 5.17 TRANSPLANTING

KEY FOR FIGURE 18
LIFE CYCLE OF THE RICE PLANT

1. STAGE I VEGETATIVE
2. STAGE II REPRODUCTIVE
3. STAGE III GRAIN FILLING AND MATURATION
4. BREAK DORMANCY
5. GERMINATION
6. BROADCAST SEED
7. SEEDLING EMERGENCE
8. THIRD LEAF
9. FIFTH LEAF (1ST TILLER)
10. TRANSPLANTATION (3RD TILLER)
11. FOURTH TILLER
12. PANICLE INITIATION (SEPT. 23)
13. PANICLE DIFFERENTIATION
14. FLOWERING AND FERTILIZATION (OCT. 23)
15. MATURATION
16. MATURITY & HARVEST (NOV. 23-25)
17. COLEOPTILE AND RADICLE DEVELOPMENT
18. ACTIVE TILLERING
19. PANICLE DEVELOPMENT
20. PANICLE LENGTH (cm)
21. MOST ACTIVE GRAIN FILLING
22. STARCH ACCUMULATION STOPS
23. MOISTURE LOSS
24. PLANT HEIGHT (cm)

FIGURE 5.18 LIFE CYCLE OF THE RICE PLANT



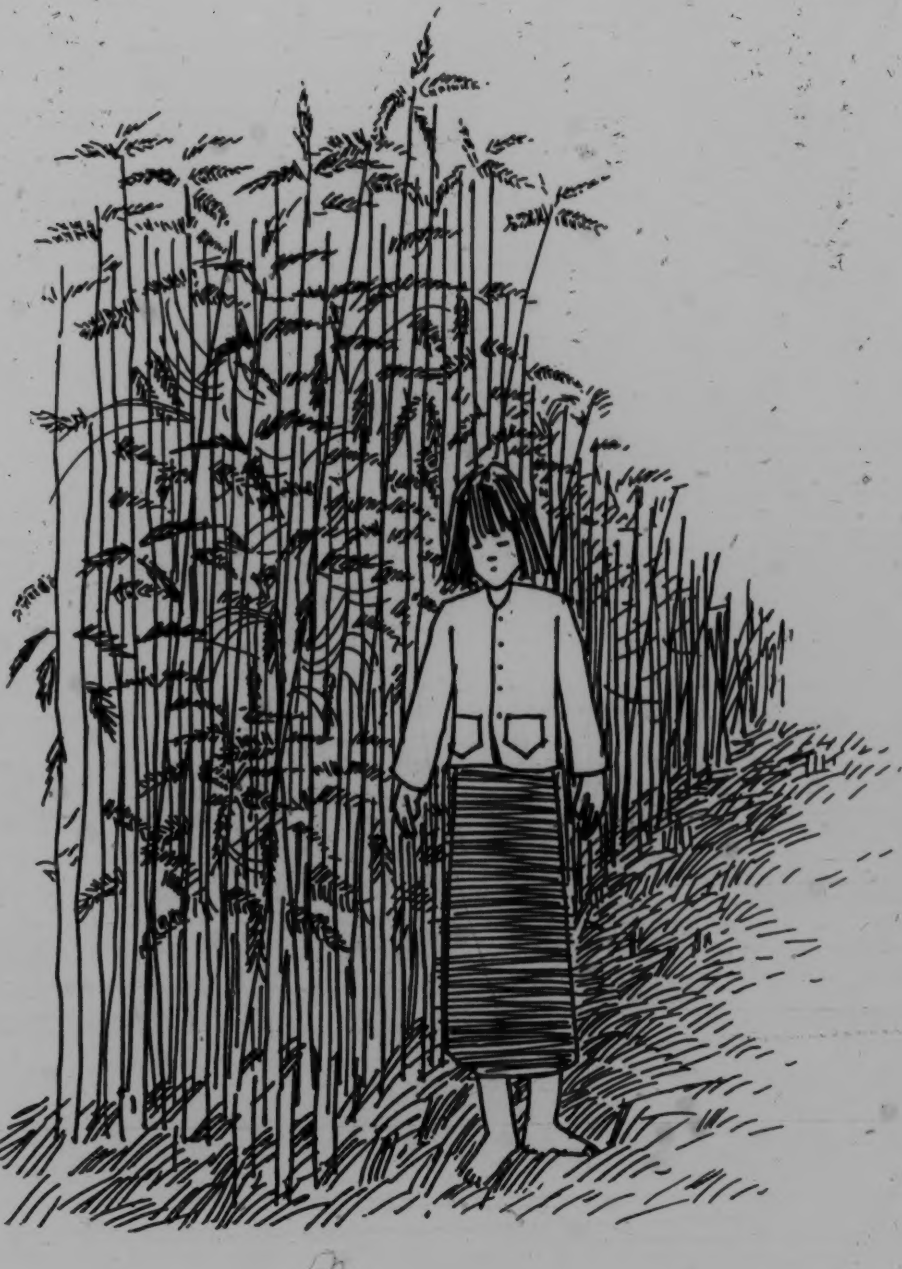


FIGURE 5.19 SESBANIA ROSTRATA FOR SEED

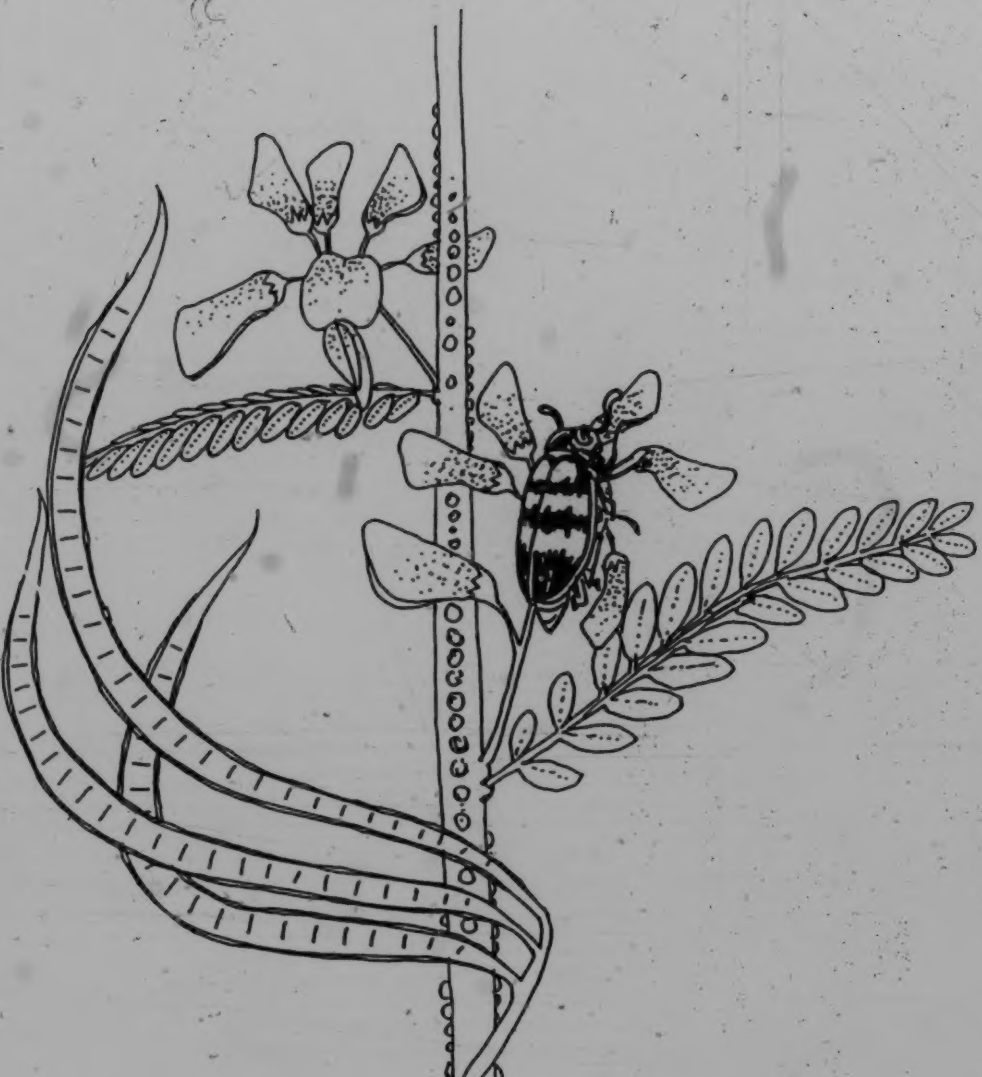


FIGURE 5.20 SESBANIA ROSTRATA - SEED POD, FLOWERS, AND FLOWER-EATING PEST

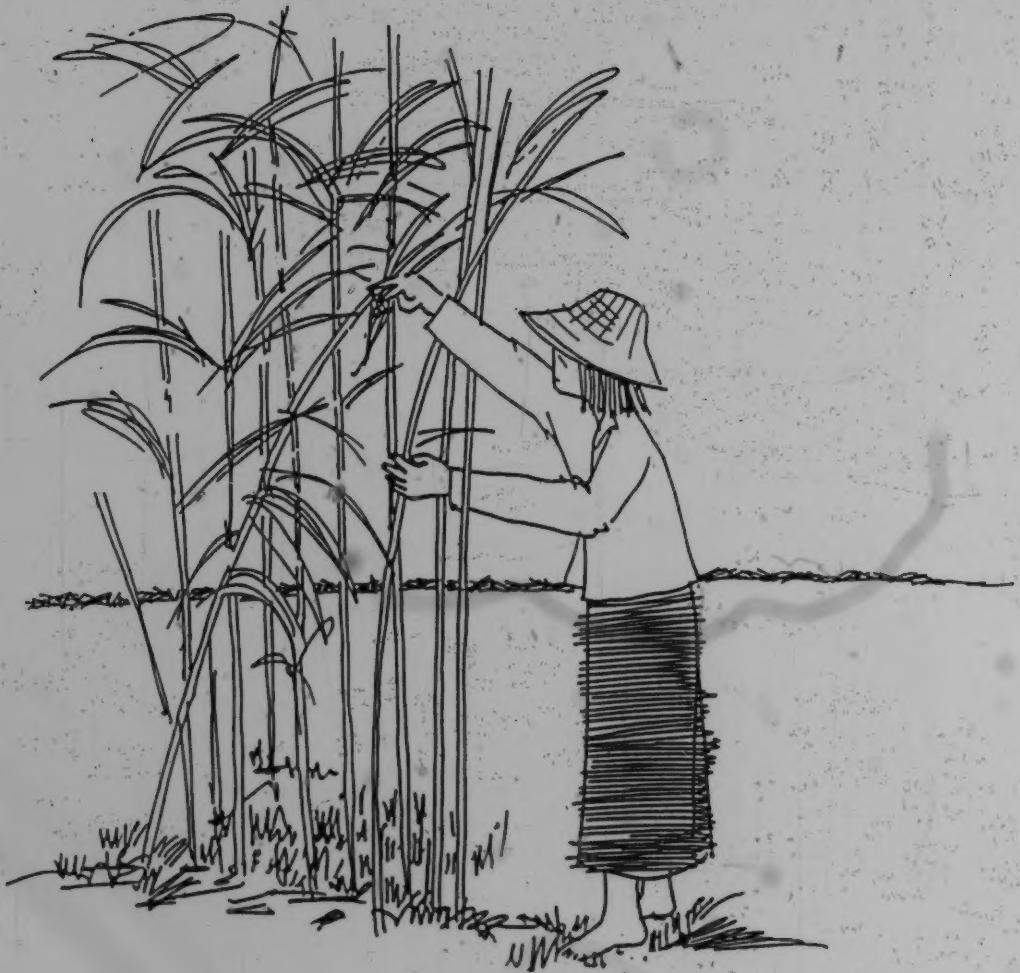


FIGURE 5.21 PICKING MATURE SESBANIA ROSTRATA PODS IN OCTOBER

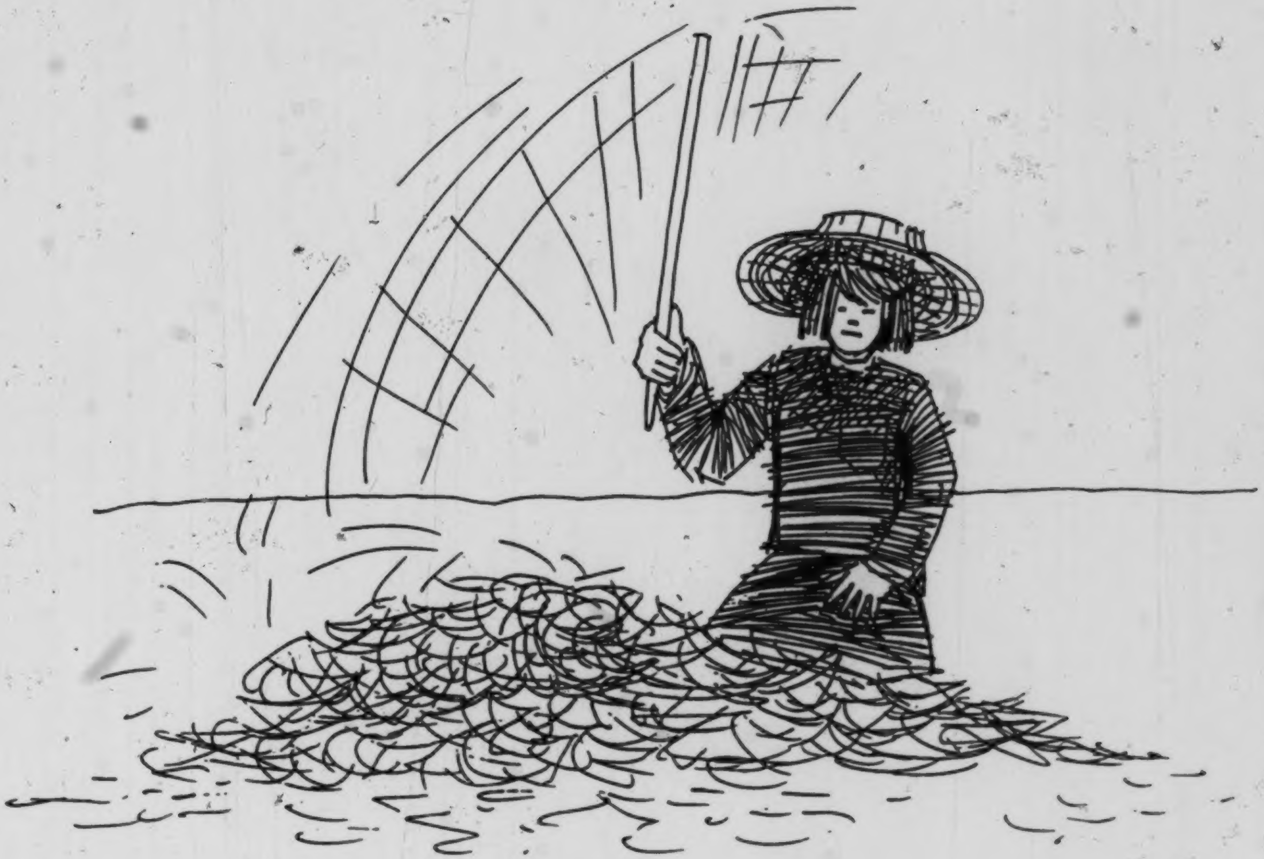


FIGURE 5.22 THRESHING THE PODS FOR SEEDS

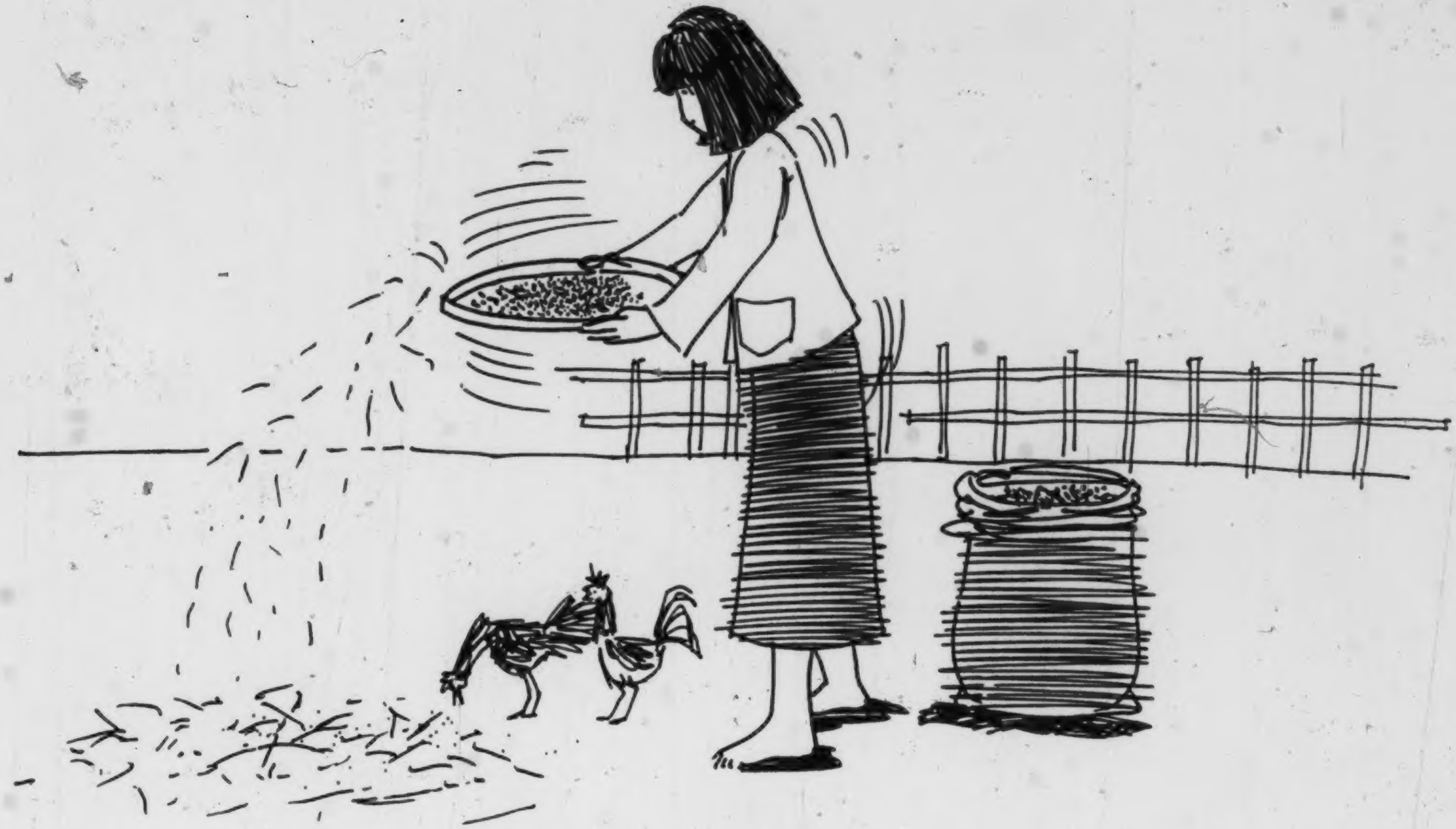


FIGURE 5.23 WINNOWING SESBANIA ROSTRATA SEED, AND STORAGE

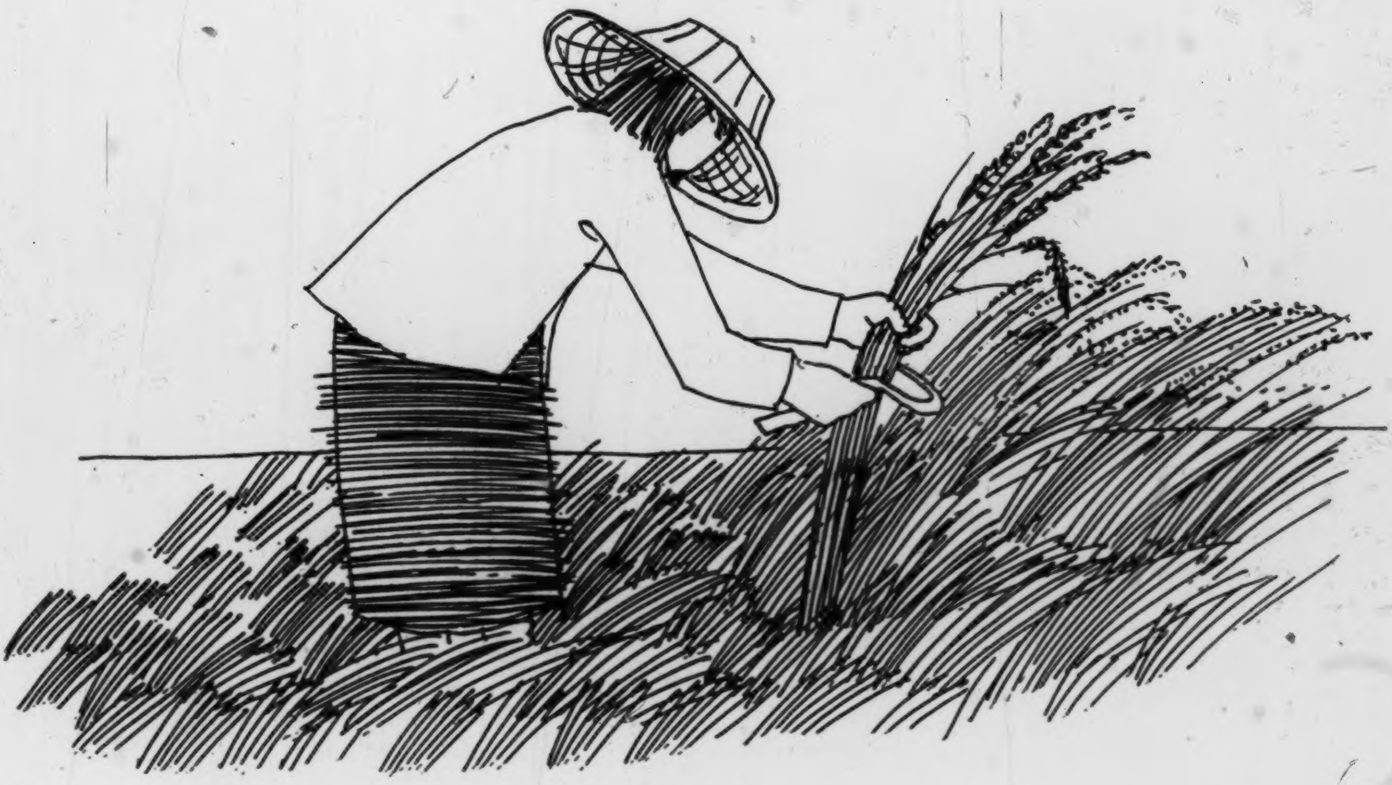


FIGURE 5.24 SWATHING RICE IN NOVEMBER

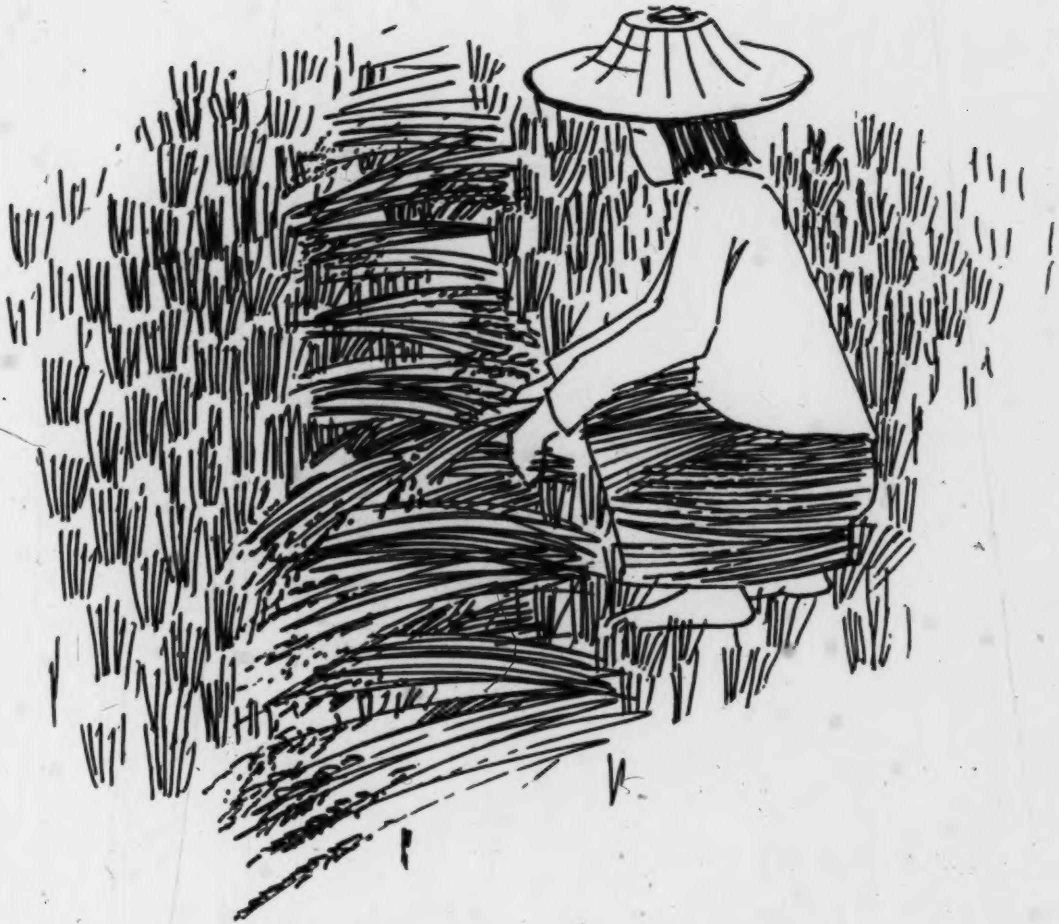


FIGURE 5.25 SUN DRYING RICE

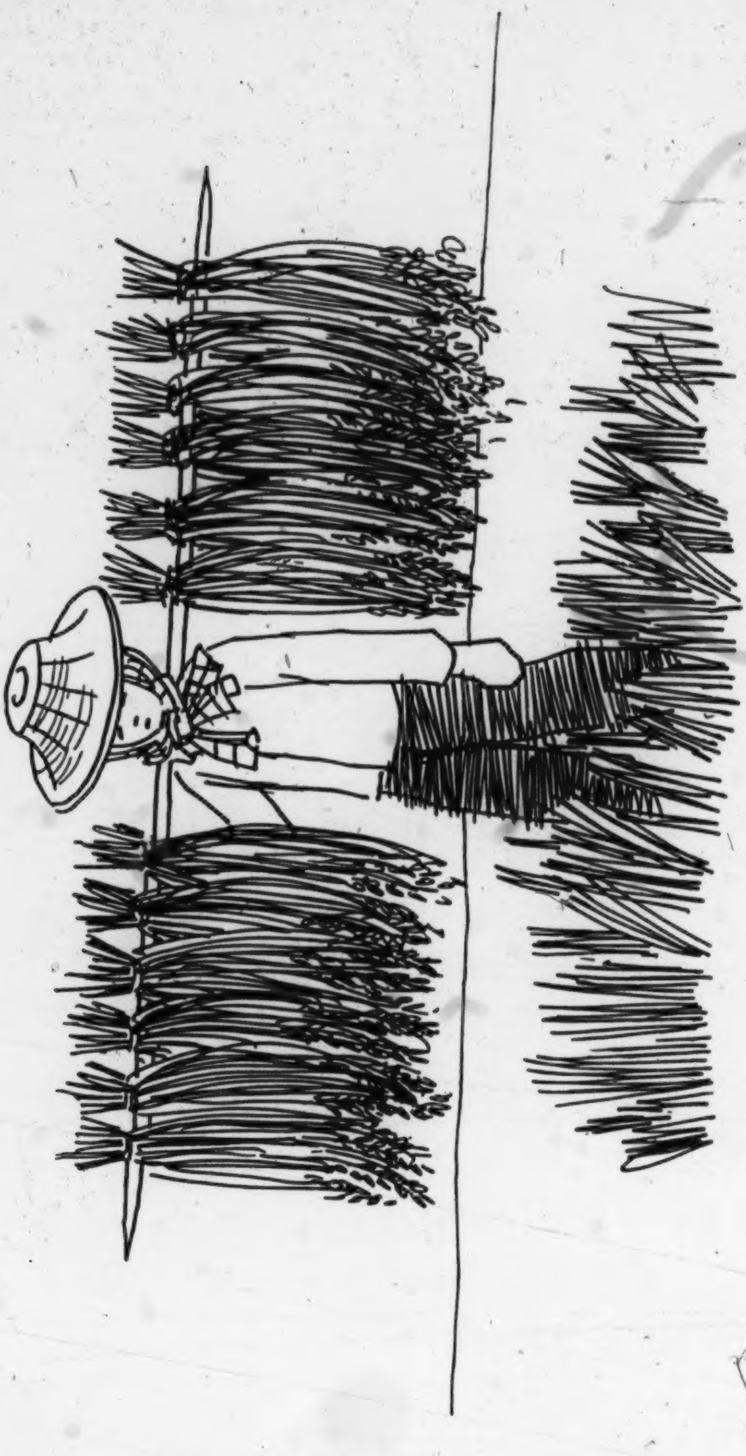


FIGURE 5.26 TRANSPORTING SHEAVES OF RICE TO THE THRESHING FLOOR

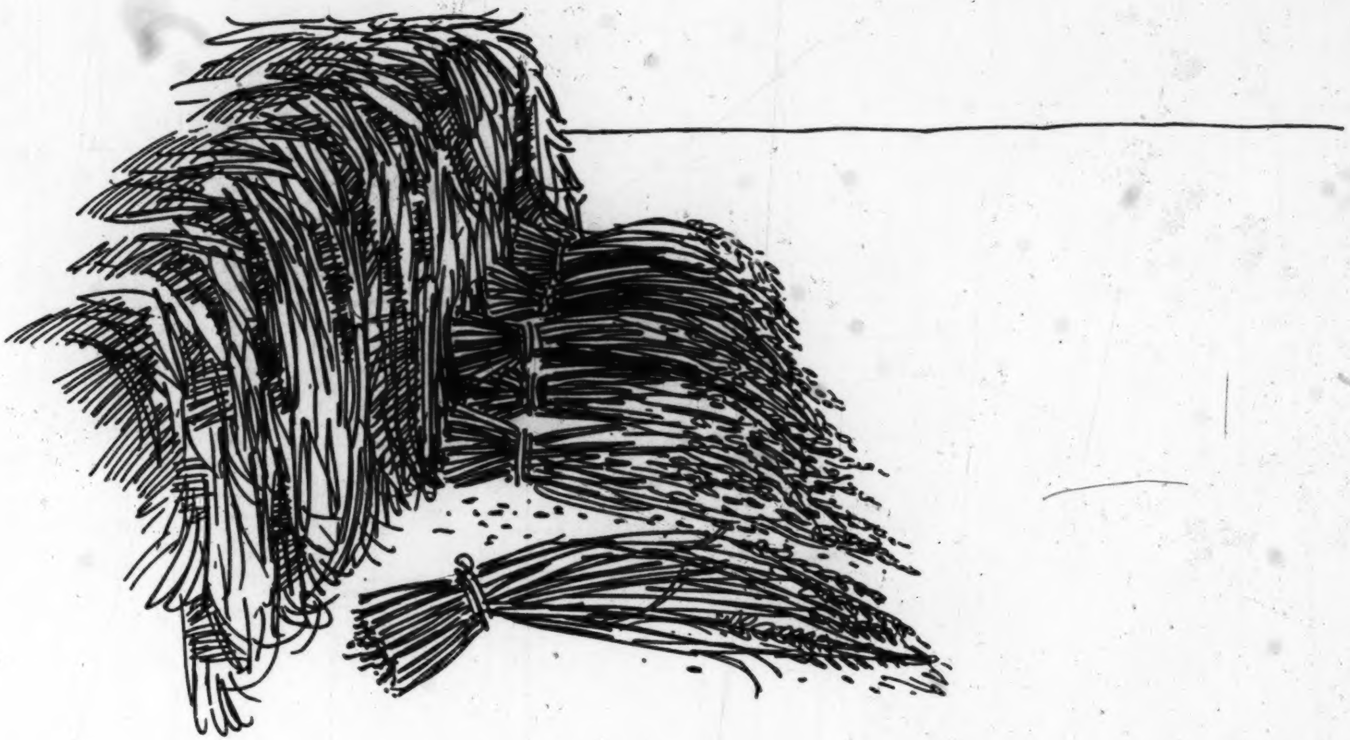


FIGURE 5.27 STACKING THE SHEAVES

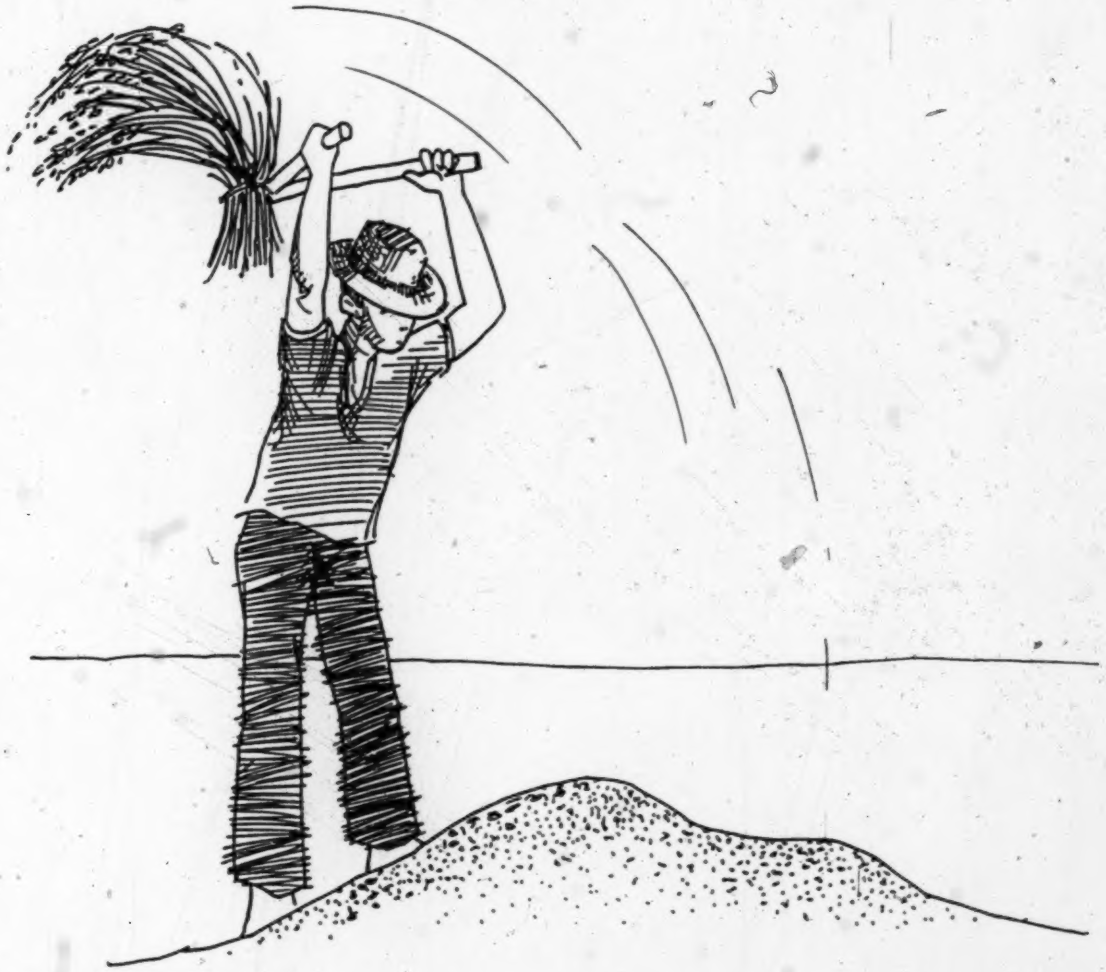


FIGURE 5.28 THRESHING

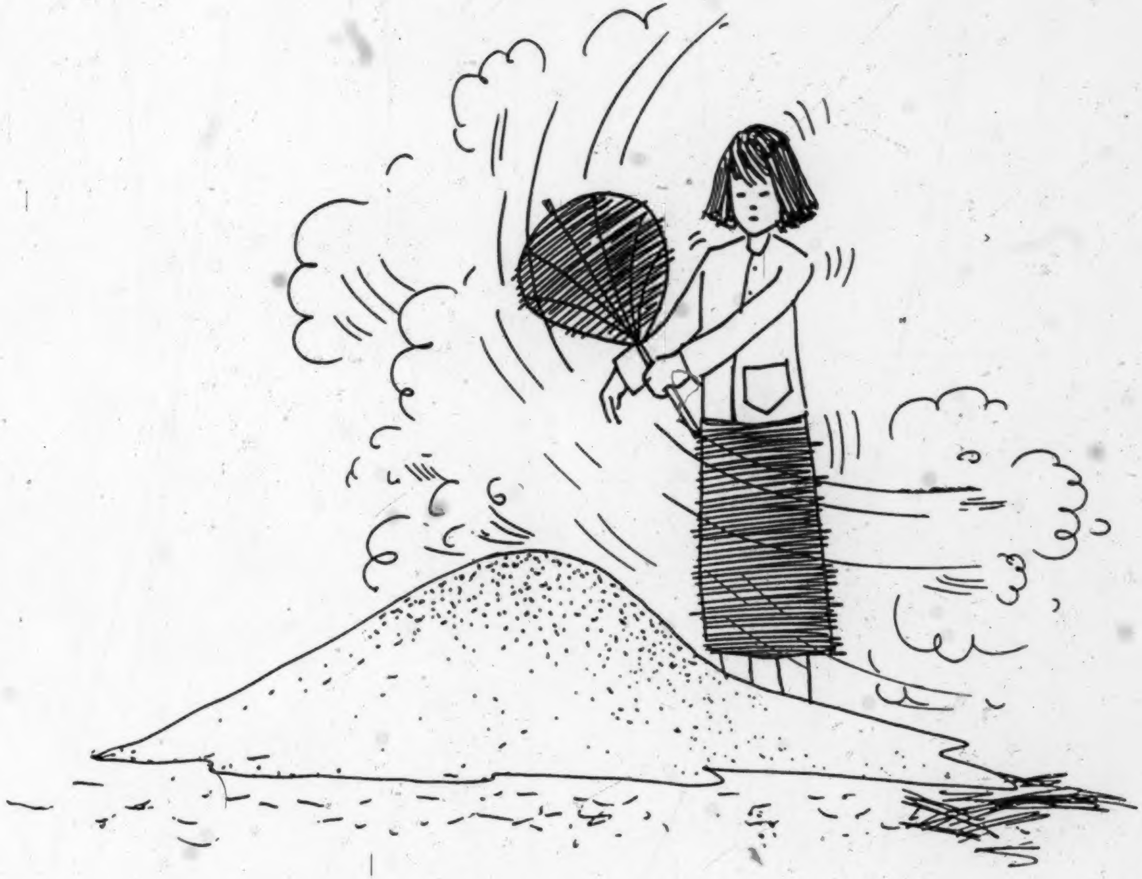


FIGURE 5.29 WINNOWING

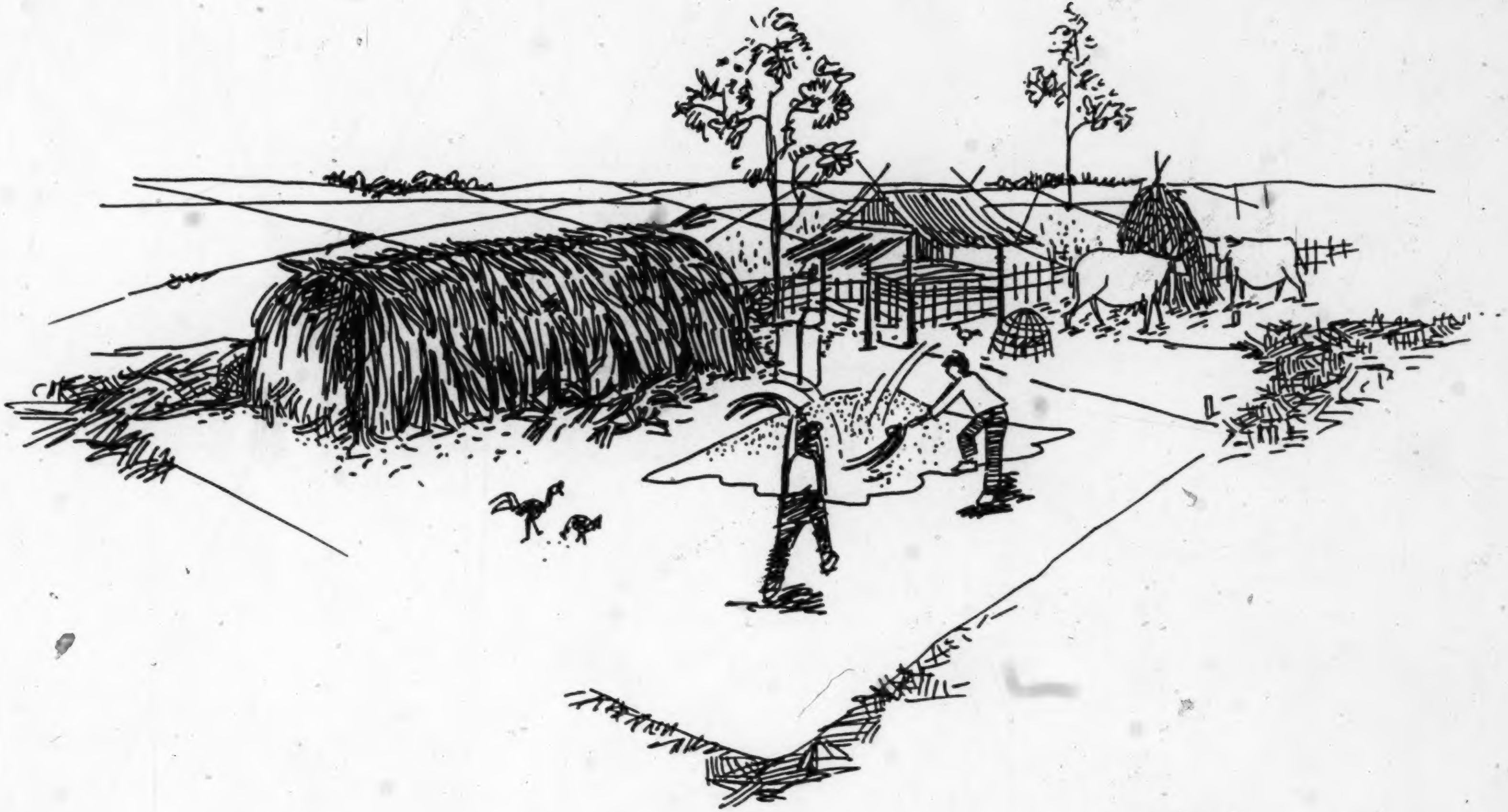


FIGURE 5.30 TYPICAL FARMYARD AT HARVEST TIME

APPENDIX 2 Socio-economic Assessment of Green Manuring with S. rostrata.

Based on the grain yield (See Chapter 4) and the expenses for each treatment (See Table 6.1), the cost benefit (See Table 6.2) of green manuring was calculated. The income gained by greater grain yields offset the cost of the treatments and exceeded the income from control plots on: DM88 FGM and GM, DM89 GM, and PY89 GM. Evidently, green manuring is economical, when there is sufficient rainfall.

Despite the observed benefit of green manuring with *S. rostrata*, the popularization of the practise faces the following obstacles: the reluctance of farmers to expend time, energy, and fertilizer for a crop that cannot be eaten by man, or used as animal fodder; the reluctance of farmers to work in the intense heat of May and June (planting time for the green manure); the intolerance of *S. rostrata* to drought; the poor availability of *S. rostrata* seed; and the need of fodder for water buffalo, which will otherwise graze the green manure crop. It is possible that with extension, farmers in areas with adeqate rainfall or a source of irrgation water will be convinced to adopt green manuring to increase their grain yields.

TABLE 6.1 Expenses incurred for each treatment *per* hectare.

Costs in $US:	Rice + FGM	Treatment Rice + GM	Rice alone
1st ploughing	31.25	31.25	31.25
S. rostrata seed	2.08	2.08	-
Broadcast Sesbania	1.67	1.67	-
Fertilizing Sesbania	50.50	-	-
2nd ploughing	36.46	36.46	36.46
Nursery preparation	10.00	10.00	10.00
Uprooting rice	25.00	25.00	25.00
Transplantation	41.67	41.67	41.67
Rice harvest	26.67	26.67	26.67
Threshing	26.67	26.67	26.67
Total:	251.97	201.47	197.72

TABLE 6.2 Cost Benefits of green manuring: FGM versus GM versus CTL.

		Rice grain (Mg ha-1)	Gross income (0.1375$ kg-1)	(Gross - Costs) ($)
	DM88			
FGM		3.03	416.63	164.66
GM		2.00	274.59	73.12
CTL		1.49	204.88	7.15
	RDM89			
FGM		1.23	169.13	-28.60
GM		1.24	170.50	-27.22
CTL		1.28	176.00	-21.72
	DM89			
FGM		2.73	375.38	123.40
GM		2.56	351.73	150.26
CTL		2.21	303.42	105.70
	PY88			
FGM		0.19	26.40	-225.57
GM		0.29	40.15	-161.32
CTL		0.23	32.18	-165.55
	RPY89			
FGM		0.27	36.99	-214.98
GM		0.27	36.71	-164.76
CTL		0.07	9.90	-187.82
	PY89			
FGM		1.92	264.52	12.55
GM		1.75	240.98	39.51
CTL		1.56	214.98	17.26

Costs and prices are indicated in $US.